

YUKON RIVER BASIN STUDY

PROJECT REPORT: ENERGY No. 6

YUKON ENERGY INVENTORY

AND

UTILIZATION REVIEW

BY

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INTRODUCTION AND REPORT OUTLINE

The terms of reference for this report call for an analysis of all existing information on the potential availability, suitability and cost of alternative energy sources for Yukon. They specifically call for a review and summary of all available resource inventory information; a review of the costs, limitations and advantages of utilizing various energy forms to meet Yukon requirements; and an analysis and recommendations on areas for further study and on potential implications for future hydro development.

In accord with these terms of reference this report is divided into three sections. Section I contains the Yukon energy inventory review. The magnitude and location of five renewable and five non-renewable sources of energy are discussed. Degree of accessibility of the resources and degree of certainty of the estimates are also discussed. Section II contains the energy utilization review. In the first part of this section, the costs, limitations and impacts of utilizing alternative energy sources are assessed source-by-source. In the second part, the sources suitable for each sector of demand are considered together in order to compare them in specific applications. Section III contains the conclusions and recommendations of the report.

It should be recognized that in a review of this broad nature, the estimates and analysis are rough. They provide only order-of-magnitude indications of the availability and relative merits of alternative energy sources. The study should therefore be viewed as a guide to what may be attractive and beneficial for Yukon, subject to further more detailed analysis. The study suggests directions that Yukon should consider; it does not provide definitive answers.

I. ENERGY INVENTORY

1.0 INTRODUCTION

The purpose of this component of the study is to describe as thoroughly as available data permits, the inventory of energy sources in Yukon.

An attempt is made to identify the total magnitude and location of potential energy resources and to classify this potential in terms of such characteristics as degree of certainty, accessibility and status of development.

It should be noted that classification systems vary between energy sources and that data limitations prevent detailed classification in some cases.

Energy resources in Yukon can be divided into two categories: renewables and non-renewables. The energy potential of renewables, including hydro-electric, wood, wind and solar is expressed in terms of annual flows. The potential of non-renewables is expressed most easily as a store or stock of energy. Table I.1 summarizes the energy potential of renewables in terms of constant annual flow and non-renewables as total stocks. In most cases these estimates represent ultimate

potential, abstracting from technical, economic and environmental constraints. Overall energy potential is not estimated because of lack of data, measurement problems and the difficulty of reconciling stocks and flows.

With respect to renewables, the energy potential from wind and solar is immense. However, the nature of these sources is such that quantitative estimates of energy potential are not meaningful. Hydro-electric power and wood are the most extensively utilized indigenous energy sources in Yukon even though they represent only a fraction of renewable energy potential available. Electrolytic hydrogen can be viewed as an alternative form of hydro-electric energy potential. The magnitude and quality of geothermal resources is unknown. Non-renewable energy sources in Yukon are essentially comprised of hydrocarbon resources.⁽¹⁾ Oil and gas reserves are the most important of these resources and potentially very large. Estimates of energy potential from peat are not available.

(1) Uranium resources in Yukon have not been included in the energy inventory.

TABLE I.1
Summary of Energy Potential in Yukon
by Source

Renewables (GJ x 10⁶/yr.)

Hydro-Electric ^a	208
Wood and Wood Waste ^b	16
Geothermal	n.a.
Wind	n.a.
Solar	n.a.

Non-Renewables (GJ x 10⁶)

Oil ^c	20,480 - 38,480
Natural Gas ^c	8,760 - 19,300
Propane ^c	325 - 675
Coal ^d	1,000 - 2,000
Peat	n.a.

- (a) Potential annual availability of electrolytic hydrogen is about 145 x 10⁶ GJ/yr based on estimate of hydro-electricity not required for direct consumption in Yukon.
- (b) Energy content of total estimated standing green timber volume available for energy purposes plus that of the waste derived from sawmill timber.
- (c) Based on ultimate potential, i.e. all of the oil, gas and propane in known sedimentary basins regardless of producibility.
- (d) Energy content of resources which can be measured or inferred from existing data.

2.0 INVENTORY BY ENERGY SOURCE

2.1 Hydro-Electric

(a) Description

Virtually all rivers in Yukon can be developed by utilities or individuals to produce electric power. Generation facilities, basically consisting of a dam which creates head and diverts stream flow to drive a turbine generator, can range from micro or small scale (i.e. generally defined as 5 MW capacity or less) to larger scale units of many hundreds of MW capacity.

The capacity or maximum power output of a hydro plant is determined by the rated output and number of turbines at the facility. The firm energy capability or the amount of energy which can be delivered throughout the year depends on the size of generating equipment and the volume of water which can be stored by the facility and drawn upon during periods of low water flows. The capacity factor is defined as the average power output of a plant divided by installed capacity.

Hydro-electricity in Yukon is used for space heating, lighting and the operation of appliances, tools and machinery in the residential/commercial sectors. In the industrial sector the single most important use is in the mining sector for ore processing and handling.

(b) Method of Inventory Measurement and Data Sources

There have been a number of studies over the past 30 years which have assessed hydro-electric potential in Yukon. However, none of them has been comprehensive in terms of site and river coverage and there have been wide variations in the underlying assumptions and depth of analysis.

The most important was a series of inventories conducted by the Water Resources Branch of the Department of Northern Affairs over the 1962-66 period, covering the Yukon mainstem, Teslin, Pelly and Stewart Rivers in Central Yukon, the Yukon-Taiya, Yukon-Taku diversion schemes in the southwest, and the Porcupine, Peel and Rat River region in the northern Yukon.⁽¹⁾ Although dated, this series of studies is probably the most in-depth of all hydro inventories conducted for Yukon since they were based to a greater extent on on-site investigations and detailed project lay-outs. Later studies frequently relied on these inventories for base data.

T. Ingledow and Associates Ltd. conducted a survey of hydro sites in the Liard River basin in the central and southeast Yukon in 1968 and 1970 respectively.⁽²⁾ This inventory was compiled on the basis of an in-house review of previous studies, hydrological and topographical data as well as a helicopter reconnaissance survey.

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- (1) Water Resources Branch, Department of Northern Affairs, Yukon River Basin Report, December, 1962; Hydro-Electric Power Resources of the Porcupine, Peel and Rat River Region, April, 1965; A Preliminary Appraisal of the Yukon Taiyu and Yukon-Taku Storage and Power Schemes, August, 1966.
- (2) T. Ingledow and Associates Ltd., Hydro-Electric Resources Survey of the Central Yukon Territory, January, 1968; Power Survey of the Liard River Basin, Yukon and Northwest Territories, February, 1970.

A more recent inventory was undertaken in 1975 by Sigma Resource Consultants for the Northern Canada Power Commission.⁽¹⁾ Based on an aerial field survey and a review of previous studies covering all the major river systems in Yukon, this study identified 100 sites and ranked the more promising power developments on the basis of cost and environmental and social impacts.

The only known overall estimate of power potential in Yukon was made by the Montreal Engineering Co. in a presentation to the Northern Development Conference of 1976⁽²⁾ based on a review of previous studies and streamflow and topographic maps.

The Montreal Engineering Co. has recently undertaken a review of previous hydro-electric inventories for NCPC and compiled the latest streamflow and topographic data from these studies. This inventory generally covers sites of 5 MW capacity or greater. The Yukon Electric Company is also initiating an inventory of small scale hydro sites in Yukon. Results from these studies were not available for purposes of this report. At this time all that can be provided is an estimate of total hydro-electric potential in Yukon as determined by Monenco in 1976, estimates of potential for the major river systems in Yukon based on the studies by the Water Resources Branch and T. Ingledow and a ranking of some of the more promising sites as described by Sigma Resources.

(1) Sigma Resource Consultants, The Development of Power in the Yukon, January, 1975.

(2) W.J. Smith, Energy Resources in Northern Canada: Hydro, November 1976.

(c) Magnitude and Location of Hydro Resource by Area

Total hydro power capacity on the major rivers in Yukon was estimated in 1976 by the Montreal Engineering Company⁽¹⁾ at approximately 11,000 MW. This corresponds to an energy capability of about 208.1 million GJ per year. It is likely that this estimate far exceeds actual hydro potential because of environmental and economic constraints.

Only about 100 MW of this potential has been developed at Mayo, Aishihik and Whitehorse (including the 20 MW "Fourth Wheel" nearing completion at Whitehorse). The 138 kV interconnected grid includes the Whitehorse hydro and diesel plants, the Aishihik hydro plant and the Faro diesel plant. A small isolated system powered by the Mayo hydro plant, supplies the town of Mayo, other local communities and the Keno Hill mine.

Based on a number of previous studies, estimated hydro potential for the most important river systems and diversion schemes in Yukon is summarized in Table I.2. It should be noted that these studies overlap in their coverage of sites and that the development of some sites affect power output at others. For example, the Yukon Taiya/Taku diversion schemes would reduce water storage on the headwaters of the Yukon and therefore reduce the firm flow and energy output of downstream sites on the mainstem. On the other hand, development of the

(1) W.J. Smith, op. cit. Assumes 60% capacity factor. Firm energy is usually based on critical energy flows.

Pelly, Stewart and Teslin Rivers would increase upstream storage and firm up capacity on Yukon. Therefore the energy potential from the various systems is not additive. Also, the assumptions and data underlying these estimates vary significantly making comparisons difficult. Figure I.1 shows the main river systems in Yukon which have been investigated for hydro potential.

TABLE I.2

Hydro-electric Potential of Major River Systems
in the Yukon

	<u>Installed Capacity</u>	<u>Energy Capability</u>
	(MW)	(GJ x 10 ⁶ /year)
Yukon River ^a	4,477	84.7
Yukon-Taiya Diversion ^b	4,050	76.6
Yukon Taku Diversion ^b	3,700	70.0
Porcupine, Peel, Rat River Region ^c	2,000	37.8
Pelly, Stewart and Teslin Rivers ^d	1,740	32.9
Liard, Frances, Beaver Rivers ^e	550	10.4

- (a) Water Resources Branch, Department of Northern Affairs and National Resources, op. cit., December, 1962.
- (b) Water Resources Branch, Department of Mines and Technical Survey, op. cit., August, 1966. These are alternative projects.
- (c) Water Resources Branch, Department of Northern Affairs and National Resources, op. cit., April, 1965.
- (d) T. Ingledow & Assoc., op. cit., Jan., 1968. Includes a number of small developments on the other rivers in the central Yukon.
- (e) T. Ingledow and Assoc., op. cit., February, 1970.
- (f) Energy capability estimated on basis of 60% capacity factor.

(d) Breakdown of Hydro Resources

The most recent major inventory of hydro sites in Yukon was undertaken by Sigma Resource Consultants for the Northern Canada Power Corporation (NCPC) in 1975.⁽¹⁾ This study identified approximately 100 sites throughout Yukon with an energy capacity of 30 MW or greater. Each of these sites was assigned to six levels of study ranging from "primary" to "unpromising" depending on an assessment of its importance as a development possibility. The hydro-electric potential of 16 of the most promising sites covering the most important river systems in Yukon is summarized below.

(i) Level One: Selected Primary Sites:- This level is comprised of 10 sites and 13 projects which appear to be most promising as the next hydro plant in Yukon. The sites are generally located in southern Yukon and reasonably close to present and foreseeable load centres.⁽²⁾ These projects have a total installed capacity of 1800 MW corresponding to about 34.1 million GJ energy capability.⁽³⁾

(ii) Level Two: Selected Secondary Sites:- This level is comprised of 4 sites and 7 projects which would provide energy at attractive costs if the corresponding upstream plant listed under (i) above were in place or with appropriate diversions to regulate flows. These projects have a total installed capacity of 1400 MW and energy capability of 26.5 million GJ.

(1) Sigma Resources Consultants, op. cit., January, 1975.

(2) Aberdeen Falls on the Peel River and the Bell site on the Porcupine are located in the northern Yukon. These were included to provide complete geographical coverage, but because of their distance from existing and possible load centres, are not considered viable sites at this time.

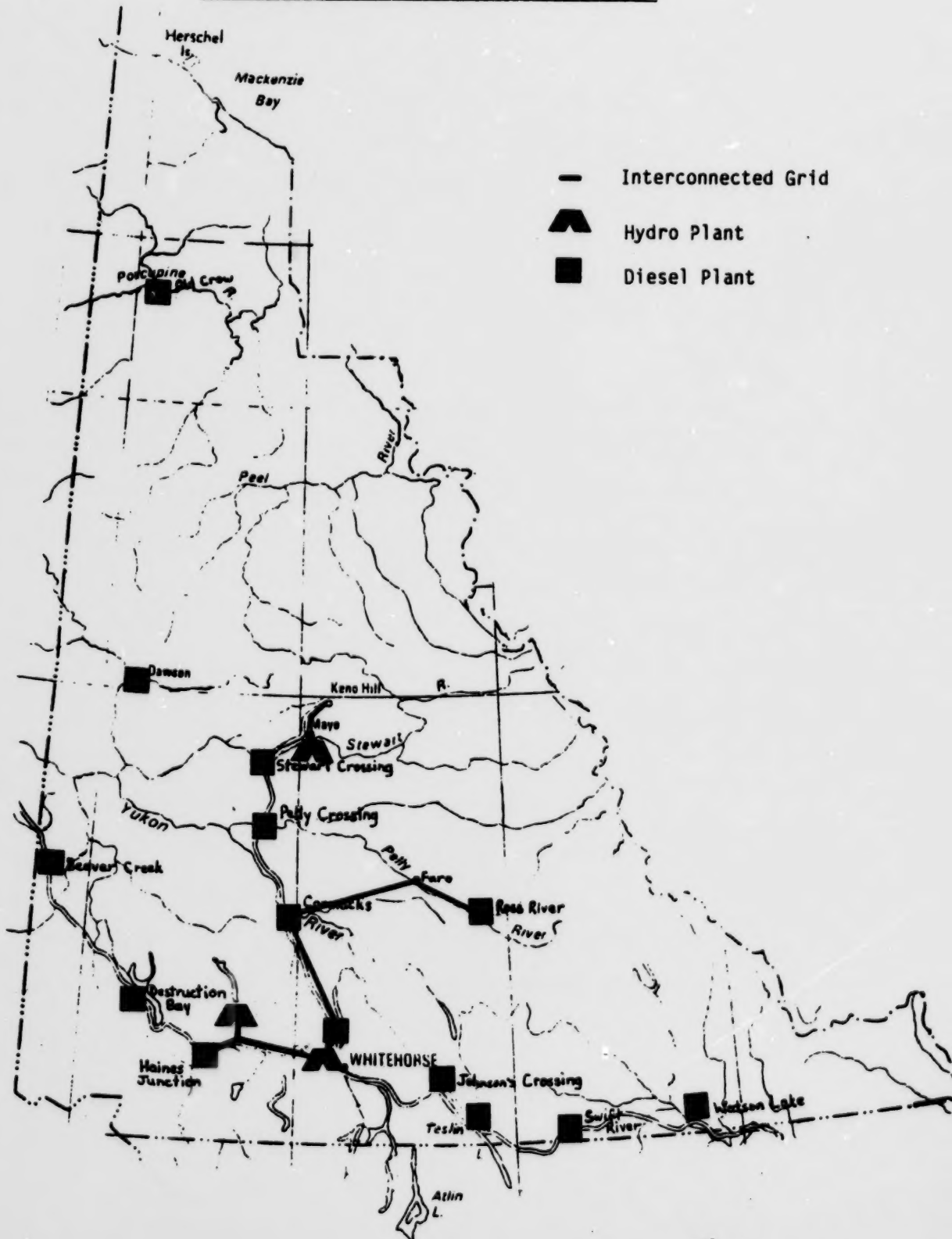
(3) Energy capability estimates based on 60% capacity factor.

(iii) Level Three: Potential Sites:- This level is comprised of 3 sites and 4 projects with good potential for future development. These projects have a total installed capacity of 365 MW and energy capability of 6.9 million GJ.

The above 16 sites and 24 projects have a total installed capacity of 3565 MW and an energy capability of 67.5 million GJ, or approximately one-third of the total hydro potential estimated for Yukon as a whole.

FIGURE I.1

Major River Systems in Yukon
Investigated for Hydro-Electric Potential



2.2 Oil, Natural Gas and Propane

(a) Description

Oil, natural gas, and propane are considered together in this section because they have similar sources of supply. All are produced from underground oil and gas reservoirs, even though they can have totally different end uses.

Oil is refined to yield various grades of gasoline, diesel, fuel oils, asphalts, and lubricants. As such, its principal end-uses are for transportation, space heating, or process heat. Natural gas, on the other hand, is utilized principally for space heating or process heat and, since it is not easily stored, it is not as useful as a transportation fuel. Propane, however, (along with other liquid petroleum gases) is easily stored and is useful for residential heating and potentially, transportation.

Recent innovations have suggested that both natural gas and propane will see increased usage as transportation fuels. Compressed natural gas and methanol (derived from methane) are both technically viable transportation fuels and are currently in use in southern Canada. Similarly, propane has potential uses in automobiles as a replacement for gasoline.

The oil and gas inventory below includes all of the indigenous sources of oil and gas in Yukon. Substantial resources lie in the areas of the Beaufort Sea and in the Alaskan North Slopes. Although Yukon will have access to these reserves if they are developed, it is anticipated that any availability will be principally on an "off-line" sales basis and that ownership of the resource is not within the political jurisdiction of Yukon.

(b) Method of Inventory Measurement and Data Sources

Oil and gas resources are presented in terms of three categories, each corresponding to a different level of certainty:

- (i) Proven reserves;
- (ii) Probable Reserves;
- (iii) Ultimate Potential.

Proven reserves refer to those resources which are known to exist and which are producible under current technologies and current economic conditions. Probable reserves include likely extension due to expected extent of the reservoirs or expected future economic conditions. Both proven and probable reserves include only the oil producible using conventional primary and enhanced recovery techniques. Up to 70% of the oil and gas may not be recoverable because of reservoir characteristics. The "ultimate potential" is a measure of all of the oil and gas in the sedimentary basins, regardless of its accessibility or producibility.

Oil and gas estimates are based on currently available studies and literature, and no explicit studies have been done for indigenous propane resources. Propane is, however, a constituent of natural gas and a range of estimates has been made for propane depending upon whether the gas is "wet" (containing high fractions of propane-plus hydrocarbons) or "dry" (containing principally methane and some ethane).⁽¹⁾

We have relied principally upon available sources from the Geological Survey (GSC) and from the Department of Indian and Northern Affairs. Another study, regarding feasibility of natural gas and propane distribution systems in Yukon has been undertaken for the Department of Tourism and Economic Development by Stone, Webster Canada. Also, a 10 year research report on sedimentary potential in Eastern Yukon will shortly be published by GSC in the same period (Memo #401). These sources have not be incorporated into our inventory.

For the current assessment, the consultants relied on the following references:

- (i) D.I.N.A., Oil and Gas Activities, Annual, Ottawa, 1981.
- (ii) C.S.P.G. Memo #1, Future Petroleum Provinces of Canada; Their Geology and Potential, 1973:
 - "Central Cordilleran Region:", N. Koch;
 - "Tathlina Area", deWit, et. al.;
 - "Peel Plateau", Kunst;
 - "Eagle Plain Basin", H.L. Martin;
 - "Old Crow Basin", J. Lawrence;
 - "Beaufort Sea", M. Lerand.

(1) Most methane is known to have resulted from the outgassing of coal seams and is not petroleum-derived.

(c) Magnitude and Location of Oil, Gas and Propane Resources by Area

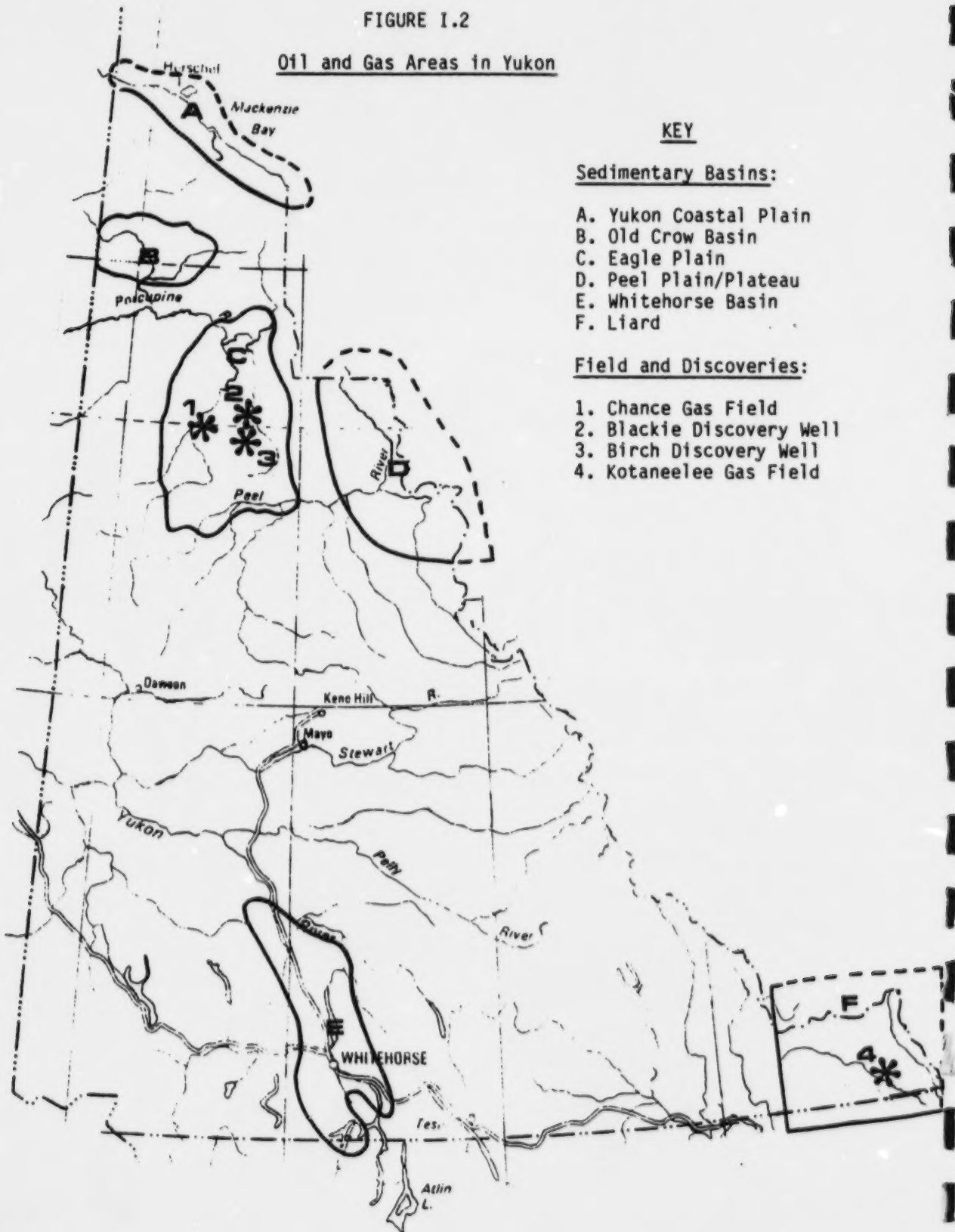
There are six sedimentary basins in Yukon with oil and gas potential. These areas are shown in Figure I.2. Of these regions, successful drilling has only been undertaken in the Eagle Plains, Peel, and Liard basins. Oil and gas discovery wells were drilled in the Eagle Plains area, and a number of gas discoveries were made in the Liard District. Indications were that hydrocarbons had migrated through the Peel Plateau area, although no significant accumulations were found. The three other areas, the Yukon Coastal Plain, the Old Crow Basin, and the Whitehorse Basin, all have oil and gas potential although no wells have ever been drilled in these areas. A summary of successful oil and gas discoveries in Yukon is shown in Table I.3.

(i) Yukon Coastal Plain

The Yukon Coastal Plain represents the southwest fringe of the Mackenzie Basin, which in total has an estimated ultimate recovery of 4-6 billion barrels of oil ($0.7 - 1.0 \times 10^9 \text{m}^3$ oil). The main-land potential of the small part of the basin which occurs in Yukon has not been evaluated as exploration is hindered by complex faulting and a restricted number of sands. There is, however, a very thick marine shale section in the area which could have produced significant accumulations in some of the faulted areas. To date, only two holes have been drilled in the area, one to 4300m and a second to 2100m. Both were dry and abandoned.

FIGURE I.2

Oil and Gas Areas in Yukon



This report was funded by the Yukon River Basin Committee under the terms of "An Agreement Respecting Studies and Planning of Water Resources in the Yukon River Basin" between Canada, British Columbia and Yukon. The views, conclusions and recommendations are those of the author and not necessarily those of the Energy Work Group, Yukon River Basin Committee, or the Governments of Canada, British Columbia or Yukon.

This report was prepared as a background paper for the Energy Work Group. Please refer to the Final Study Report for the view of the Yukon River Basin Study Committee.

TABLE I.3

Successful Yukon Oil and Gas Discoveries and Recoveries^a

Well Name	Completion Year	Well Status	Potential ^b
Eagle Plain			
Canoe River Chance	1968	Potential Gas & Oil	DST 184x10 ³ m ³ /d gas
Chance G-08	1965	Potential Oil	DST 93x10 ³ m ³ /d gas 360m ³ oil
Birch	1965	Potential Gas	DST 206x10 ³ m ³ /d gas
Blackie	1964	Potential Gas	DST 79x10 ³ m ³ /d gas
Chance M-08	1960	Potential Gas or Oil	DST 142x10 ³ m ³ /d gas 0.5 m ³ /d oil
Liard			
Beaver River I-27	1964	Suspended Gas Test	AOF 43x10 ³ m ³ /d gas
Kotaneelee H-38	1977	Gas Well	592x10 ³ m ³ /d gas
Kotaneelee E-37	1978	Suspended Gas	
Kotaneelee I-48	1980	Gas Well	AOF 12,931x10 ³ m ³ /d gas
Beaver River G-01a	1969	Abandoned Gas	AOF 192x10 ³ m ³ /d gas
Beaver River G-01b	1969	Abandoned Gas	AOF 1120x10 ³ m ³ /d gas

(a) Source: Oil and Gas Activities, D.I.N.A., 1981.

(b) DST = Drill Stem Test; AOF = Absolute Open Flow.

(ii) Old Crow Basin

Estimates of hydrocarbon potential in this basin are based on surficial geology and seismology. The remoteness of the area has discouraged exploration and no wells have been drilled to date. As such, only an estimate of the volume of sedimentary rock can be made. Lawrence estimated some 12,000 km³ miles of sediment. This would possibly yield 10 million m³ of recoverable oil and some 6 billion m³ of gas.⁽¹⁾

In terms of the region's development potential, Lawrence observes that:

Any production found in the Old Crow basin would eventually be tied in to pipelines either from the Mackenzie Delta or from Prudhoe Bay. A line from Prudhoe Bay would probably cross the Old Crow basin. Pipelines from the Mackenzie Delta probably would be in the order of [62.5 km] from any production at Old Crow, therefore, for such production to be economic reserves in the order of [3 to 8 million m³] would be required. In the case of pipelines from Prudhoe Bay crossing the Old Crow basin even small reserves might be economic.

(iii) Eagle Plain

The oil and gas potential of the Eagle Plain is about ten times that of the smaller Old Crow basin to the northwest. Although five discovery wells have been drilled in the area, none are currently commercial. An estimate of the ultimate oil and gas potential of the basin was made by Martin, based on a volumetric comparative assessment.

(1) Note that estimates of recoverable or probable reserves are based on assumed recovery factors of .3 and .7 for gas and oil, respectively.

Drilling and seismology indicated a basin size of about 123,000 km³ having a recoverable oil reserves of some 90 million m³ and recoverable gas of about 68 billion m³.

(iv) Peel Plain/Plateau

The Peel Plain/Plateau area lies to the east of the Richardson Mountains and extends well into the Northwest Territories. Although most of the surficial area lies outside of Yukon, more than half of the sediment in the basin lies in the Peel Plateau, which is principally in Yukon. Prolific gas discoveries have been made in this basin along the Mackenzie River, and wells drilled on the Yukon side of the border have also indicated oil and gas shows. Kunst estimates that the Yukon Peel/Plateau region contains about 140,000 km³ of sedimentary rock, with oil reserves ranging from 54-190 million m³ and gas reserves of 57-200 billion m³. He comments that "whereas the potential reservoir thickness is sufficiently great to harbor a billion barrel pool, it is more realistic to expect a number of smaller pools, say in the (4 to 16 million m³) size range."

Currently, there is no infrastructure to market these reserves and, as with the other on-shore basins, it seems that their exploitation will depend upon the construction of a pipeline through the Mackenzie Valley.

(v) Whitehorse Basin

The Whitehorse Basin is the northernmost of a series of successor basins which extend right through central British Columbia. Unlike the basins in northern Yukon, analyses indicate that historical temperatures in the Whitehorse basin never exceeded 250°C, implying that dry gas (methane) is likely to be the main hydrocarbon present, with possible shows of ethane. Propane and heavier hydrocarbons are not likely to be found in the basin. Koch estimates that, from a sedimentary volume of 61,000 km³, between 25 and 16 billion m³ of gas reserves may be found in tightly folded anticlinal traps.

(vi) Liard Plateau

This basin has been the target for two successful gas discoveries: one at Beaver River in Yukon and a second at Pointed Mountain in the NWT. The area is in the far southeast corner of Yukon and currently serves Westcoast Transmission pipelines into British Columbia. The structural trap of the Beaver River anticline is a well-defined structure of 25 kilometers long and 7 kilometers wide. Proven reserves of gas for this area are about 40 billion m³, most of which is dry, sweet gas. Drill-stem tests indicated that the gas composition included 88.48% methane, 0.63% ethane, 0.62% hydrogen sulfide, and 10.27% non-hydrocarbon inert gases.

(d) Breakdown of Oil and Gas Resources

A summary of the oil and gas potential for the regions are given in Table I.4.⁽¹⁾ It indicates a total ultimate oil potential for Yukon in the order of $0.5-1.0 \times 10^9 \text{m}^3$ (representing an energy content of about 20-40 billion GJ) and gas potential of $280-610 \times 10^9 \text{m}^3$ (representing an energy content of about 9-19 billion GJ). Probable reserves of oil and gas represent approximately 30% and 70% respectively, of ultimate potential.

With respect to propane resources, they are not explicitly estimated. One can however, obtain an approximate estimate based upon the oil and gas estimates above. Excluding the Whitehorse Basin and Liard Plateau, both of which are considered to contain essentially dry gas, the Yukon ultimate gas potential is $186-391 \times 10^9 \text{m}^3$. In the western sedimentary basin the propane/gas ratio is approximately $0.0684 \times 10^3 \text{m}^3$ of liquid propane for every 10^6m^3 of gas. Based on this estimated ratio, the potential liquid propane resources of Yukon are in the order of $13-27 \times 10^6 \text{m}^3$. This energy content of these propane resources is equivalent to about 325-675 million GJ.

(1) Energy conversion factors for oil, gas and propane are assumed as follows:

- Oil (light to medium grade) - 40 GJ/m^3
- Gas - $.0314 \text{ GJ/m}^3$
- Propane - 25 GJ/m^3

TABLE I.4
Summary of Oil and Gas Resources
 (m³ x 10⁹)

Basin	Probable Reserves		Ultimate Potential	
	Oil ^a	Gas ^b	Oil	Gas
Yukon Coastal Plain	N/A	N/A	N/A	N/A
Old Crow	.010	6	.032	8
Eagle Plain	.090	68	.300	97
Peel Plateau	.054-.0190	57-200	.180-.630	81-286
Whitehorse Basin	--	25-116	--	36-166
Liard Plateau	--	40	--	57
TOTAL:				
m ³ x 10 ⁹	.154-.290	196-430	.512-.962	279-614
GJ x 10 ⁹	6.16-11.6	6.15-13.5	20.48-38.48	8.76-19.3

(a) Based on assumption of a 30% recovery ratio.

(b) Based on assumption of a 70% recovery ratio.

2.3 Coal

(a) Description

Coal, is one of the readily mineable fossil fuels which still harbours significant potential for development all across Canada. Whereas the value of coal has tended to escalate in many areas at the same rate as its closest substitutes - oil and gas -- the costs of exploiting the reserves of coal have remained relatively constant since the quality and quantity of the resource base has seen little degradation. As such, coal has started to receive much more attention recently as an important energy alternative.

Depending upon its quality, coal can be used as an input for making metallurgical coke, it can be burned to generate heat or it can be converted to liquid and gaseous fuels. Our central concern in Yukon is its use as thermal coal. Thermal coal has traditionally been used at a very local level for space heating. On a larger scale, however, it is successfully used by the manufacturing industry directly as a source of process heat (such as for smelting) or indirectly as a fuel for firing steam driven electric generators.

A distinct advantage which coal has over other fossil fuels is that it is generally cheaper and easier to store and transport. A disadvantage is that the environmental effects of coal use are typically more deleterious, in that coal ash and sulphurous by-products are generated from its combustion.

Coal is found in a continuously variable sequence of grades and qualities. It is not possible to generate a single objective ranking of coal grades, since its value will to a large extent depend upon its intended end-use. One method of ranking, however, involves classification by the amount of fixed carbon⁽¹⁾ there is in a sample and by the calorific value. Generally, a higher amount of fixed carbon has a greater heating or calorific value.⁽²⁾ From high value to low value, then, coal can be classified as follows:

- a. Anthracitic
- b. High Volatile Bituminous
- c. Low-Medium Volatile Bituminous
- d. Sub-Bituminous
- e. Lignitic.

The lower rank coals have higher moisture content and lower heating values than higher rank coals, and, in addition, they are commonly non-agglomerating (i.e., they do not hold together) and are subject to spontaneous combustion. Although widespread occurrence of coal has been noted in Yukon (see below), most of them are high-volatile, bituminous and lignitic coals. The bituminous coals hold some potential as metallurgical coal, thermal coal and for coal gasification, and the lignitic coals may have potential for small-scale mine-site use or for small-scale electric generation.

(1) Fixed carbon is the residual remaining after the moisture, volatile combustible material and ash content have been determined.

(2) Volatile components have heating value as well.

(b) Method of Inventory Measurement and Data Sources

In addition to the variety of grades which one encounters when evaluating coal resources, there is distinct uncertainty in the physical extent of the resource base. "Coal resources" generally include all of the coal in the ground regardless of quality, depth, seam thickness, etc. This measure is of passing interest only and a more useful measure includes only those resources which can be measured or inferred from existing data, and which occur within areas exploitable with current technologies. Such measured and inferred resources are considered here.

It should be noted that this resource measurement excludes any economic considerations of exploitation. Economic coal "reserves" depend upon the price of the coal and its extraction and utilization costs. Once again, in this resource inventory, we will exclude any such economic considerations and consider the resource base alone.

In some cases it has been possible to derive a tonnage estimate of the coal resource from estimates of the seam thickness and extent. In other cases, it has only been possible to identify sites of outcrops or drilling activities where coal resources have been identified as sufficient for future small-scale development.

The Yukon Department of Economic Development is currently undertaking a coal inventory which will soon be completed. The resources identified herein reflect those estimates from presently available studies, including:

- (i) Milner and Craig, Coal Areas in the Yukon, unpublished mimeo, 1978.
- (ii) Bielenstein, et. al., Coal Reserves of Canada, Energy, Mines and Resources, ER 79-9, 1979.
- (iii) Hughes and Long, Geology and Coal Resource Potential of Early Tertiary Strata Along Tintina Trends, Yukon Territory, EMRR, 79-32, 1980.
- (iv) Department of Indian and Northern Affairs, Yukon: Geology and Exploration -- 1979-80, Whitehorse, 1981.

(c) Magnitude and Location of Coal Resource

Although coal outcrops can be found in most areas of Yukon, major coal seams and beds occur in basically three areas of the Territory. The three areas, shown in Figure I.3, are the Bonnet Plume Basin, the Tintina Trench, and the Carmacks Area (or Whitehorse Trough).

(i) Bonnet Plume

Some of the most significant resources have been estimated at the Bonnet Plume Basin (65°50' N; 135°00' W). The coal is found in four seams up to about 12 metres thick, overlain by about 300 metres of conglomerate, sandstone, and shale. The area has been drilled on a 1 kilometer grid and 650 million tonnes of thermal grade high volatile coal have been delineated, representing an energy content of about 3.25-6.50 billion GJ. The coal has a low ash and sulphur content. Although the resources here are significant, the major deterrents to its development are the depth of the coal and the limited accessibility to the area. The Dempster Highway corridor passes close to the area, however, and there is therefore a possibility that future development of infrastructure will make exploitation of these resources feasible.

(ii) Tintina Trench

The second major zone of coal occurrences is in the Tintina Trench, which is an area stretching from the Dawson vicinity in the west-central region down to the Watson Lake area in the southeast corner. The infrastructure in this region is also quite limited. Very little exploration work has been done, but a number of deposits have been identified which could be commercially exploited on a small scale. Most of the occurrences are less than a few metres thick, and would support at best a small electric generation site for 10-20 years.

FIGURE I.3

Coal Areas in Yukon

KEY

A. Bonnet Plume Basin

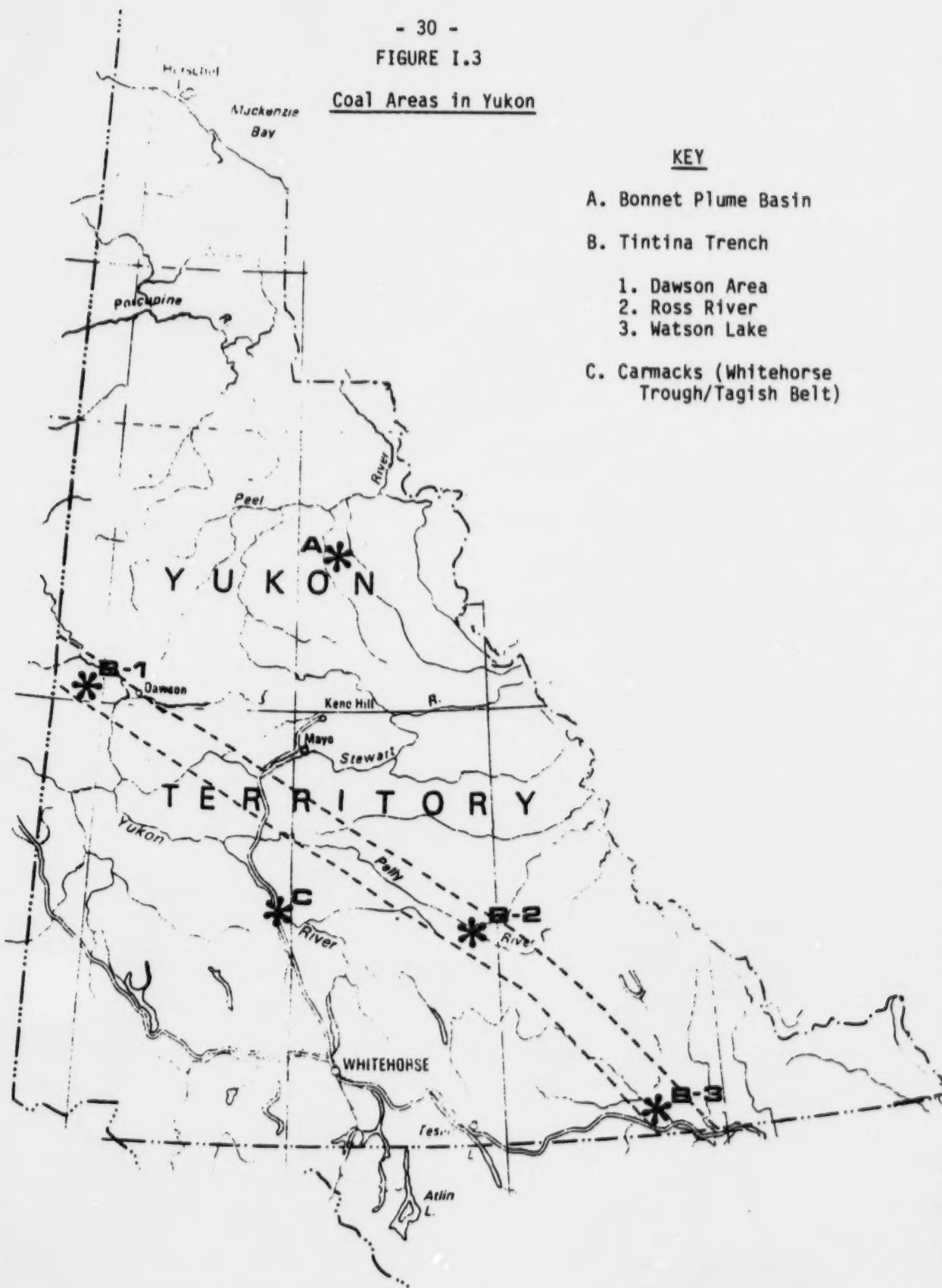
B. Tintina Trench

1. Dawson Area

2. Ross River

3. Watson Lake

C. Carmacks (Whitehorse
Trough/Tagish Belt)



Three areas within the Tintina Trench have been found to contain coal deposits. The Dawson Area (64°30' N; 140° W) contains the thickest seams of coal, although the coal is mostly lignitic and sub-bituminous. One 60 cm thick seam of high volatile bituminous coal has been exposed along the Yukon River near the Alaska border. This area did have three operating mines at the beginning of the century supplying thermal coal for local use. No resource estimate for the area exists, although the shallow depth of the coal and the extent of the tertiary strata in the region suggests that mineable deposits exist.

The Ross River block (61° 58' N; 132° 32' W) of the Tintina Trench contains somewhat higher quality thermal coals ranging from low volatile to high volatile bituminous. A seam about 2.7 m thick mineable along the Canol Road is of major interest, having inferred resources of 0.37-1.10 million tonnes, representing an energy content of 1.9-11.1 million GJ. Other observed seams were too small to meet current resource criteria.

The Watson Lake coal area lies in the Liard Plain, beyond the southern limit of the Tintina Trench (60°N; 129°W). No resource estimates have been made, although the coal is generally of very low quality. Typical seam thickness is of the order 50 cm, and the coal is all lignitic. It is estimated that most occurrences are lenticular and of limited lateral extent, and the glacial cover is typically very thick over the entire region. In short, although the resources can be found in the area, prospects of mining it are poor.

The overall resource potential of the Tintina Trench was summarized as follows by Hughes and Long:

The probable small size of mineable deposits along Tintina Trench will restrict mining to small-scale operations. They may, however, be sufficient to supply electricity for local use. The Ross River area appears to hold the most promise for early exploitation because of high rank, moderate structural complexity and good access. The Dawson area coals may ultimately prove to have larger resources, but their remote location, lower rank and higher degree of structural complexity will require a relatively large exploration expenditure to ascertain their true potential. Resource potential of Watson Lake area coals is limited by their low rank, structural complexity and extensive surficial cover.

(iii) Carmacks Area

The Carmacks area (62°30'N; 137°W) is in the northern part of a coal bearing region known as the Whitehorse Trough/Tagish Belt. Coal has been produced from 4 mines in this area in the past, one of which (the Tantalus Butte mine) was used recently as a source of thermal coal for plant heating and drying ore concentrate at Cyprus Anvil's lead-zinc mine at Faro. No resource estimates for the area have been undertaken, although it is useful to review what is known about the mine-sites in the area.

The first mine in the area, the Five Fingers Mine, was staked in 1898 and produced from a number of locations. Mineable seams up to 1.5 metres thick were found. A second mine was staked in 1910, 8 kilometers southeast of Fort Selkirk. Good quality bituminous coal was reported, but there are currently no signs of the mine.

The major mining sites in the area are at the Tantalus and Tantalus Butte mines. About 125,000 tonnes of bituminous coal were mined early in the century from the Tantalus mine from three separate seams 1 metre, 2 metres and 2 1/2 metres thick. These seams were also known to recur 5 kilometers to the North and 30 kilometers to the south. The Tantalus Mine was shut down in 1922 and the shallower Tantalus Butte mine commenced operation. This mine has been mining a 3 metre thick seam of bituminous coal. Although the resource potential of the entire region has not been formally evaluated, the coal bearing region could be as large as 50 square kilometers in extent.

Known coal bearing regions in Yukon are summarized in the table below.

<u>Area</u>	<u>Coal Reserves</u> (Tonnes x 10 ⁶)	<u>Energy Content</u> (GJ x 10 ⁶)
Bonnet Plume Basin	650	3,250 - 6,500
Tintina Trench		
Dawson	n.a.	n.a.
Watson Lake	n.a.	n.a.
Ross River	.37 - 1.10	1.9 - 11.1
Carmacks	n.a.	n.a.

2.4 Peat

(a) Description

Peat has recently been recognized as an important potential energy source in Canada, as Canada contains the second-highest quantity of peat resources in the world. Peat is partially decomposed organic matter, formed very slowly by the decay of mosses, and other aquatic plants. Peat is the first step of decay of organic matter and, when subjected to high pressures of many eras, forms coal. There is, however, no reason to believe that current peat resources are in any way correlated with coal resources, since peat is essentially dependent upon recent biological and environmental conditions (up to 10,000 years ago) whereas coal formations are dependent on conditions millions of years ago. As such, peat is a biological resource and it falls into the category of biomass energy.

Peat in its natural state consists primarily of water and, before it is useful, it must be dried to reduce the moisture content by about one-half. This drying process can take years and is most efficiently done at the site of the peat bog by drainage ditches. Once drained, the bog is levelled and heavy machinery can be used to remove the peat. Harvested peat is marketable in sod form for industrial use as a thermal fuel for firing boilers and steam generators, or it can be compressed into briquettes for smaller scale purposes such as home heating. It can also be used as a source of methane for methanol production, which is a potential transportation fuel.

Although most of Canada's peatlands are in the south, Yukon also contains substantial peat resources. The primary difference, however, is that Yukon's resources lie in permafrost areas. This fact does not change the usefulness of the peat, but it does affect its accessibility since it is less easily drained and dried under these conditions.

(b) Method of Inventory Measurement and Data Sources

There are basically four factors which enter into the determination of peat potential.

- (a) areal extent;
- (b) thickness;
- (c) moisture content;
- (d) volume of organics.

The first two factors influence the volumetric determination of the resource base. Moisture content determines the volume of "dried" peat which can be eventually obtained. Finally, the amount of organic materials in the peat will determine its useful energy content. It should be noted that moisture content is typically of the order of 90% under natural conditions and 40% for dried peat. In permafrost, natural moisture contents still averages 90% although some of it may be found in solid ice lenses or layers.

Very little in the way of detailed peat inventory work has been done in the Yukon Territory. Most of the current information is based on air-photo interpretation and selected soil and surficial geology studies. A program of field work is being undertaken during the summer of 1983 by the Geological Survey and Agriculture Canada in the central Yukon to estimate the resource potential in one small area.

The description of known resources in the following sections is largely based on national inventory work recently completed (unpublished) work by Dr. C. Tarnocai at Agriculture Canada. This work is preliminary in nature and may be revised within the next 2-3 months.

Documents for resource estimates are as follows:

- (i) Special Committee on Alternative Energy and Oil Substitution, Energy Alternatives, Ottawa, 1981.
- (ii) C. Tarnocai, Peatland Inventory Methodology Used in Soil Surveys, unpublished, 1982.
- (iii) C. Tarnocai, Provisional Peatland Distribution Map, Agriculture Canada, unpublished, 1983.

(c) Magnitude and Location of Peat Resources

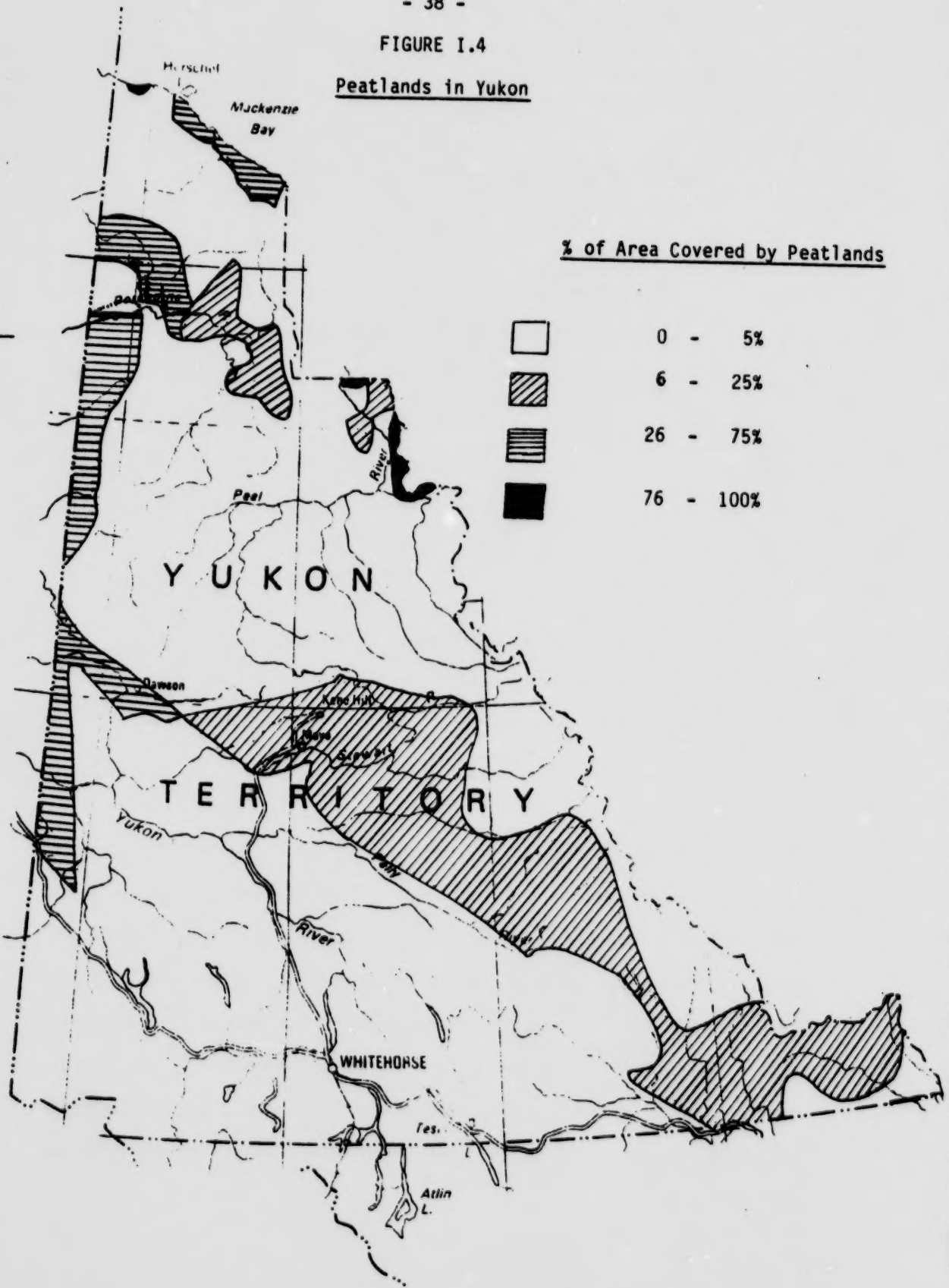
It is estimated that approximately 3% of Yukon is covered in peatlands. This represents a total peatland area of 1.3 million hectares. The distribution of these lands is shown in Figure I.4. The highest density of peatlands is found in the areas around the North Slope by the Beaufort Sea, near the Porcupine River (Old Crow area), and sites near Dawson City. No specific measurement of peat depths have been done, but the average thickness of the peat bogs in the various regions where they do exist are as follows:

- 250 cm: North Slope; Old Crow
- 200 cm: Yukon River Basin
- 100 cm: St. Elias Range; Richardson Range; MacKenzie Mountains; Peel River Basin.

Estimates of peat volumes and energy content require more specific data on peat depths and organic content than is available at this time. However, it is apparent that the most significant resources lie in the northern part of the Territory in the Old Crow and North Slope region. These areas are in the zone of continuous permafrost. Potential in the south is less marked because of the sparse distribution of peatlands, although this does not imply that individual bog areas, particularly in the Dawson vicinity, might not be used at some future date.

FIGURE I.4

Peatlands in Yukon



(d) Breakdown of Peat Resources

The existing peatland classification system for southern Canada is considered inappropriate for the north. Agriculture Canada will be recommending a revised taxonomy for peatlands in the near future.⁽¹⁾

(1) Land Resource Research Institute, Agriculture Canada, Proceedings of a Peatland Inventory Methodology Workshop, to be published.

2.5 Wood and Wood Waste

(a) Description

Yukon contains a very large volume of forest biomass. A large proportion of this forest consists of small-sized trees for which no markets exist in the foreseeable future other than for fuelwood.

There are three basic uses of wood as an energy source - for space heating, for the production of electric power and for the co-generation of both heat and power. Currently in Yukon wood is used primarily in domestic air tight space heaters. Much of the wood supply for domestic purposes is cut from firekill areas close to communities. A chip-fired space heating boiler has been installed at the Pelly Crossing School as part of the Canada-Yukon Conservation and Renewable Energy Demonstration Program.

One disadvantage of wood as a fuel, which makes its collection and transport very expensive, is its bulk and weight in relation to its energy value. Standing timber also has a high moisture content at the time it is harvested which reduces its value. Drying the wood increases its heat value per unit volume, but air-drying takes a long time and large quantities of wood have to be stored if a constant supply is to be maintained. Quicker drying in heated kilns requires additional energy. Chips can be handled more conveniently for conveyor and hopper systems, can be dried more quickly and evenly and they present a greater surface area for more efficient combustion.

Extracting selected gases, liquids and solids from wood by fermentation, pyrolysis, chemical reduction or enzymatic reduction yields fuels with greatly increased heat value per unit weight. However, most of the extractive procedures are sophisticated and relatively expensive.

Much of Yukon's forest volume consists of spruce and birch. These two species are the most highly favoured for fuel. Other species include aspen, balsam poplar, cottonwood and alder which burn more rapidly and have less heat value per unit volume.

The energy content of wood is generally expressed as a high heating value or the absolute maximum heat that can be derived from that wood. One pound of oven-dry wood of almost any kind has a similar energy content since the chemical composition of all wood is roughly the same. However, the higher the moisture content the less is the effective energy value.

(b) Method of Inventory Measurement and Data Sources

The approach taken in estimating the magnitude of the wood energy resource in Yukon is outlined as follows:

- (i) The overall timber resource in Yukon is estimated and, based on assumptions regarding the average rotation period for different species and growing terrains an Annual Allowable Cut (AAC) is calculated. The AAC represents the volume of timber which can be harvested in perpetuity.

- (ii) Annual commercial requirements for sawlogs and mining timbers are subtracted from the AAC to determine the volumes available for energy purposes. It is assumed that pulp requirements are zero for the foreseeable future due to long timber rotation periods, high access costs and high transportation costs to markets. An alternative measure of total wood energy is estimated by netting out timber volumes on more productive river valley terrace sites.
- (iii) The availability of wood waste for energy purposes is estimated on the basis of a typical waste factor for existing mills in Yukon.
- (iv) The energy available from standing timber and wood waste in Yukon is based on average energy content for hardwoods and softwoods typically found in Yukon.

The most recent and comprehensive data source for estimates of standing timber is a 1976 biophysical survey of eco-regions in Yukon by Fisheries and Environment Canada.⁽¹⁾ This study was based on field surveys, reconnaissance flights over much of Yukon and reviews of previous literature.⁽²⁾ Timber inventory and waste wood volume estimates for Yukon are summarized below.

(1) E.T. Oswald and J.P. Senyk, Eco-Regions of the Yukon Territory, Fisheries and Environment Canada, June 1977.

(2) Most notably C.H. Gairns, Reference Study on Forest Resources, Volume VIII of D.W. Carr report on the Yukon economy of 1968.

(c) Magnitude and Location of Wood Resource

As shown in Table I.5, the total timber volume in Yukon is estimated at 253.5 million cubic metres. Approximately 15% of this volume is comprised of hardwoods such as aspen, birch and poplar and 85% is softwood such as white and black spruce and pine. These estimates include only merchantable timber⁽¹⁾ and exclude standing dead timber in burned areas. The area in Yukon roughly north of the 65th parallel (i.e. eco-regions 17-22) has negligible merchantable timber and is not shown in the Table. Figure I.5 shows merchantable timber volume estimates by eco-region in the Yukon.

(1) That is, trees greater than 10 inches in diameter at a height of 1.3 meters on the tree butt up to a 4 inch top.

FIGURE I.5

Merchantable Timber Volume by Ecoregion in Yukon

Ecoregions

Timber
Volume

(³'000m)

1. Beaver River	45,184.0
2. Liard River	83,502.3
3. Logan Mountains	6,571.8
4. Pelly Mountains	13,513.5
5. Lake Laberge	31,222.0
6. Coast Mountains	1,976.5
7. St. Elias Mountains	---
8. Ruby Range	2,453.9
9. Wellesley Lake	1,776.9
10. Dawson Range	2,688.8
11. Klondike River	7,369.2
12. Pelly River	27,646.0
13. Mayo Lake-Ross River	24,473.0
14. Itsi Range	4,873.1
15. Wernecke Mountains	---
16. South Ogilvie Mountains	256.1
17. North Ogilvie Mountains	---
18. Eagle Plain	---
19. Peel River	---
20. Berry Creek	---
21. Old Crow Basin	---
22. Northern Mountains and Coastal Plain	---

TOTAL:

253,507

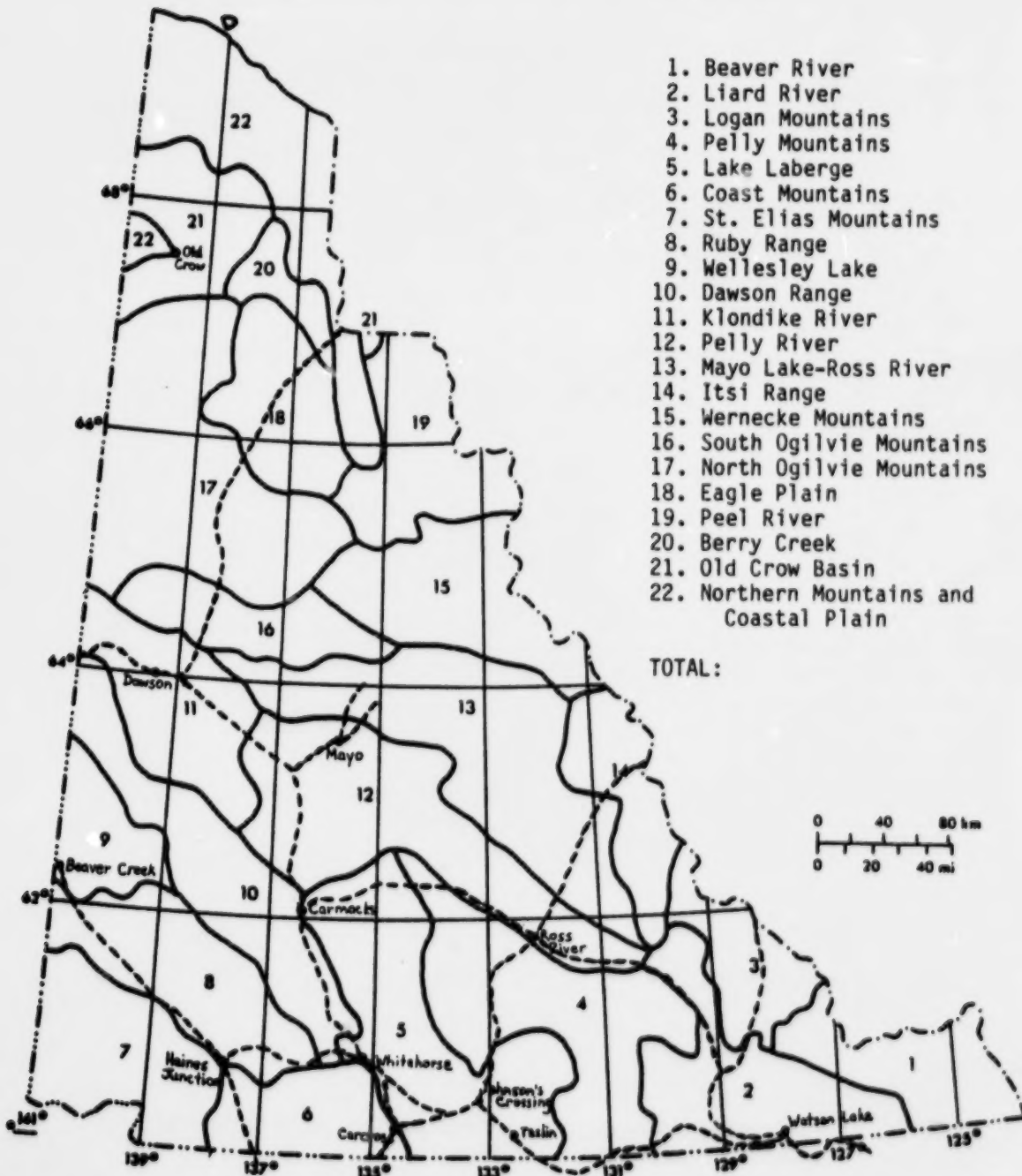


TABLE 1.5

Yukon Forest Resources Volume Summary

Eco-Region		Cover Types ('000 m ³)				TOTAL
		Softwood ^a Alluvial	Softwood ^b Upland	Hardwood ^c	Sub Total	
1. Beaver River	S ^d	7747.7	32352.4	238.6	40338.6	45184.0
	H ^e	1295.8	2309.1	1240.5	4845.4	
2. Liard River	S	8955.9	67563.3	106.9	76626.1	83502.3
	H	1497.9	4822.1	556.9	6876.1	
3. Logan Mts.	S	485.8	5590.8	2.4	6079.0	6571.8
	H	81.2	399.0	12.6	492.9	
4. Pelly Mts.	S	2132.6	10058.5	0.0	12191.1	13513.5
	H	220.5	1101.9	0.0	1322.4	
5. Lake Laberge	S	2609.1	26058.0	4.2	28671.3	31222.0
	H	268.4	2178.7	103.6	2550.7	
6. Coast Mts.	S	1005.2	835.8	0.0	1841.1	1976.5
	H	67.4	68.0	0.0	135.4	
7. Ruby Range	S	31.5	1964.2	0.0	1995.7	2453.9
	H	10.0	448.2	0.0	458.2	
8. Wellesley Lake	S	543.8	666.7	0.0	1210.5	1776.9
	H	172.5	393.9	0.0	566.4	
9. Dawson Range	S	1242.3	822.4	0.0	2064.7	2688.8
	H	387.5	236.6	0.0	624.1	
10. Klondike River	S	3420.2	1818.6	0.0	5238.9	7369.2
	H	1084.8	1045.5	0.0	2130.3	
11. Pelly River	S	5791.5	12902.3	19.2	18713.0	27646.0
	H	1775.9	6747.7	409.4	8933.0	
12. Mayo Lake- Ross River	S	4425.6	11820.0	2.7	16248.3	24473.0
	H	1375.8	6796.5	52.3	8224.7	
13. Itsi Range	S	855.3	2395.1	1.2	3251.6	4873.1
	H	250.7	1347.8	23.0	1621.5	
14. S. Ogilvie Mts.	S	154.9	32.7	0.0	187.6	256.1
	H	49.1	19.3	0.0	68.5	
TOTAL	S	39401.5	174880.9	375.2	214657.6	253507.0
	H	8537.6	27914.4	2397.5	38849.4	

- (a) Valleys and low river terraces.
 (b) Higher, more steeply sloped drier areas.
 (c) Alluvial and upland.
 (d) S = Softwood.
 (e) H = Hardwood.

There are two ways to estimate the energy available from merchantable timber in Yukon. One would be to net out sawlog, mining timber and pulpwood requirements. This would ideally require a forecast of growth in these sectors over the study period but for purposes of simplicity we assume here that annual sawlog and mining requirements equivalent to peak harvests for both of these end uses over the 1951-81 period, or about 130,000 m³/year. This estimate likely overstates average commercial requirements in Yukon in the foreseeable future. It is assumed that commercial requirements would be taken from more productive valley and river terrace sites.

There are no existing pulp mills in Yukon and because of long timber rotation periods, high access costs and high transportation costs to market, pulp requirements are assumed to be zero in the foreseeable future. This assumption is considered reasonable by DINA Forestry Service officials in Whitehorse and Ottawa.⁽¹⁾

The annual sustainable timber harvest or annual allowable cut (AAC) in Yukon can be estimated on the basis of assumed rotation periods⁽²⁾ for softwood and hardwoods in alluvial (river valley and terraces) and upland areas as summarized in Table I.6. Rotation periods assumed here likely err on the high side which results in a conservative estimate of the AAC.⁽³⁾

-
- (1) One official stated that if pulp timber were not used for fuelwood, much of it would be destroyed by forest fires by the time mills were established.
 - (2) That is, harvestable age. A more accurate estimate of AAC requires detailed knowledge of the age distribution of the forest by area and species. The above estimate implicitly assumes a homogeneous forest cover with an even age distribution.
 - (3) Because Yukon forest areas tend to be understocked, intensive forest management could likely increase the AAC in the future.

TABLE 1.6

<u>Rotation Periods by Species and Area^a</u>			
(Years)			
	Alluvial	Upland	Hardwood ^b
Softwood	120	120	100
Hardwood	60	80	80

(a) It is assumed that hardwood and softwood upland stands are harvested for fuelwood purposes only thus requiring shorter rotation periods and that all commercial harvesting is done on alluvial sites.

(b) Predominantly hardwood stands in both alluvial and upland areas.

Source: E.T. Oswald, Pacific Forest Research Centre, B.C.

On the basis of the above assumptions the AAC in Yukon available for energy purposes is estimated at 2.2 million cubic metres/year. Based on an average high heating value of 7.1 GJ/m^3 ⁽¹⁾ the above AAC represents 15.6 million GJ of energy per year.

(1) Source: Average energy content for softwood and hardwood species typically found in Yukon and Alaska as cited in Reid Collins Alaska Inc., Use of Wood Energy in Remote Interior Alaskan Communities, Sept., 1981.

Another means of estimating the magnitude of the standing forest resource available for energy purposes would be to net out the more productive valley (alluvial) and river terrace sites for commercial purposes. These sites account for roughly 20% of the merchantable timber volume in Yukon, or about 50 million cubic metres⁽¹⁾ corresponding to an AAC of 455,000 m³/year. Note that this greatly exceeds actual historical peak commercial harvests in Yukon. The above approach results in an AAC for energy purposes of about 1.8 million m³/year, with an energy content of 12.8 million GJ/year.

With respect to wood waste, an approximate estimate of annual potential volume would be 65,000 m³ - 230,000 m³ based on historical peak harvests of 130,000 m³/year or a sawmill timber allocation of 455,000 m³/yr. and a waste factor of 50%. Assuming an energy content similar to split cordwood, the annual energy availability from wood waste is estimated at .9 - 1.6 million GJ, or only a very small fraction of energy available from standing green timber.

(d) Breakdown of Wood Resources

There is very little readily available information regarding the accessibility and quality of the forest resource in Yukon. Staff at the Forest Resources Division of DIAND in Ottawa estimate that only about 3% of the timber volume is located in easily accessible and

(1) Source: Forest Resources Division, DIAND, Ottawa.

more productive alluvial soils in river valleys; about 24% in moderately sloped and productive river terraces and the remainder in more steeply sloped, drier upland areas. This categorization very roughly corresponds to the inventory compiled by Oswald and Senyk. As shown in Table I.5 above, they estimated that approximately 19% of Yukon timber volumes occur in river valley or river terrace alluvial soils, 80% in upland areas and the remainder in hardwoods on both alluvial and upland sites. It is also interesting to note that three of the most productive regions, Liard River, Lake Laberge and Pelly River, encompass the major transportation routes and population centres in Yukon.

2.6 Geothermal

(a) Description

Geothermal energy is the natural heat of the earth which continues to be generated in the earth's interior by the decay of radioactive elements. Geothermal resources occur where mechanisms exist that concentrate geothermal energy in exploitable forms at shallow depths.

Temperatures in the subsurface increase at the world wide average rate of about 30°C/km. Anomalous heat flow occurring locally in the Cordillera associated with Quaternary volcanism (such as the Wrangle Volcanic Belt in SE Yukon) or Tertiary plutons with high radiogenic heat production may give rise to temperature gradients on the order of 50-100°C. If subsurface formations are sufficiently permeable, upward migration of heated thermal waters by convection may transport heat energy to surface (hot springs) or to shallow depths that can be penetrated by drilling (3 km).

Geothermal resource may be classified according to their geological environment as follows:

(i) Hydrothermal Convection Systems

- Vapour dominated (240°C)
- Water dominated
 - high temperature (>180°C)
 - moderate temperature
 - low temperature (<120°C)

(ii) Conduction Dominated Systems

- sedimentary basins
- geopressured basins

(iii) Hot Igneous Systems

- hot dry rock
- magma

Potentially exploitable geothermal resources in the Yukon Territory taking into account current technological constraints and the geology of the Cordillera are mainly hydrothermal convection systems in areas of high heat flow. These are systems in which heated water rises to the surface as a result of temperature differences with surrounding water. In nature, low temperature systems ($<120^{\circ}\text{C}$) are much more widespread and common than intermediate and/or high temperature water-dominated systems. High temperature hydrothermal systems are restricted to areas of young volcanic activity (<5 million years). Vapour dominated systems are rare on a worldwide basis although they account for a significant proportion of geothermal system electric power. In sedimentary environments, north of the Tintina Trench, a subclass of low temperature hydrothermal systems referred to as "Rocky Mountain Type" systems occur. Subsurface water is heated because of the great circulation depths that water migrating along permeable beds or structures may attain, rather than by virtue of an anomalous temperature gradient.

Geothermal energy has been used for heating and bathing for many centuries. Geothermal power plants were first developed in Italy. Utilization of geothermal energy has been increasing at rapid pace since the early 1970's to the point where the development of proven resources can now be accomplished using standard procedures and established technology.

High-temperature geothermal water may be flashed to steam for electric power generation using steam turbines. The amount of saturated steam produced is dependent on the temperature of the resource. With currently available technology an adequate supply of thermal water at temperatures greater than 180°C is considered necessary to produce electricity. Current research is directed at developing binary fluid power generating systems (heat exchanged to secondary working fluid with a relatively low flash point, eg. freon, propane, isobutane) that operate in the moderate temperature range (120°-180°C).

Low and moderate temperature thermal waters are used for a wide variety of direct applications such as space or process heating.

In Yukon, the most obvious potential direct uses of geothermal energy are space heating for recreational facilities, commercial, institutional or apartment buildings, district heating, mine air heating, mineral concentrate drying and processing, feedwater for domestic water supply, de-icing of structures and roadway or airstrip

surfaces, and aquaculture. At the present time, the municipalities of Mayo and Whitehorse use naturally heated groundwater to a minor extent to supplement domestic water supplies in order to prevent freezing. The Takhini hot springs near Whitehorse has been developed as a recreation facility with a swimming pool.

(b) Method of Inventory Measurement and Data Sources

Studies regarding geothermal resources of the Yukon Territory serve only to indicate regions where thermal resources may exist. Exploration and measurement of specific geothermal sites within these regions has not been conducted to date. A geothermal assessment of Western Canada by Souther⁽¹⁾ indicates a broad thermal anomaly or regional zone of high heat flow associated with active crustal structures (Denali Fault System) and young volcanic terrain (Wrangle Volcanic Belt). Crandall and Sadlier-Brown⁽²⁾ report geochemical and geological data on hot spring areas in Cordilleran Yukon, Northwest Territories and northern B.C. indicating widespread occurrence of low-temperature and prospective moderate-temperature hydrothermal convection systems.

Other regional geological studies and hydrologic data bearing on geothermal potential are contained in various government reports published by the Geological Survey of Canada.

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- (1) Souther, J.G., Geothermal Potential of Western Canada. Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, May, 1975.
- (2) Crandall, J.T. and Sadlier-Brown, T.L., Data on Geothermal Areas, Cordilleran Yukon, Northwest Territories and Adjacent British Columbia, Canada, 1976.

Ultimately, geothermal resources must be proven by drilling and direct testing in a similar fashion to oil and gas or groundwater exploration. Confirmation and testing programs may range from a single well of less than 100m depth for a small direct use application, to perhaps five large-diameter production wells to depths up to 3 kilometres for large scale power projects. The resource temperature, thermal fluid production rate and energy production potential, and surface facility requirements are determined from a detailed analysis of well test data. Exploration for high temperature resources requires concerted effort over an extended period of time (4-6 years).

Prior to drilling, subsurface characteristics and potential of individual prospects may be estimated from geologic, hydrologic, geochemical and geophysical data collected during surface exploration.

Regional studies to determine the possible or probable existence of high or moderate temperature geothermal resources suitable for electrical power generation require a compilation and analysis of data on:

- 1) age and style of volcanics or intrusive activity
- 2) tectonic style and history
- 3) hot spring distribution and chemistry
- 4) available heat flow data
- 5) regional geology and hydrology

For direct-use utilization technical and cost constraints (for pipelines) dictate that the geothermal resource be located within 10-15 kilometres of the application site. Typically, for small installations, production wellheads will be within a few hundred metres. Exploration and development strategies vary greatly depending upon potential returns. Considerable resource assessment work may be appropriate for large-scale direct application systems (industrial processes, district heating). Often, however, the challenge for developers is one of identifying suitable applications at sites close to known resources or reserves that can be proven at a minimum cost risk.

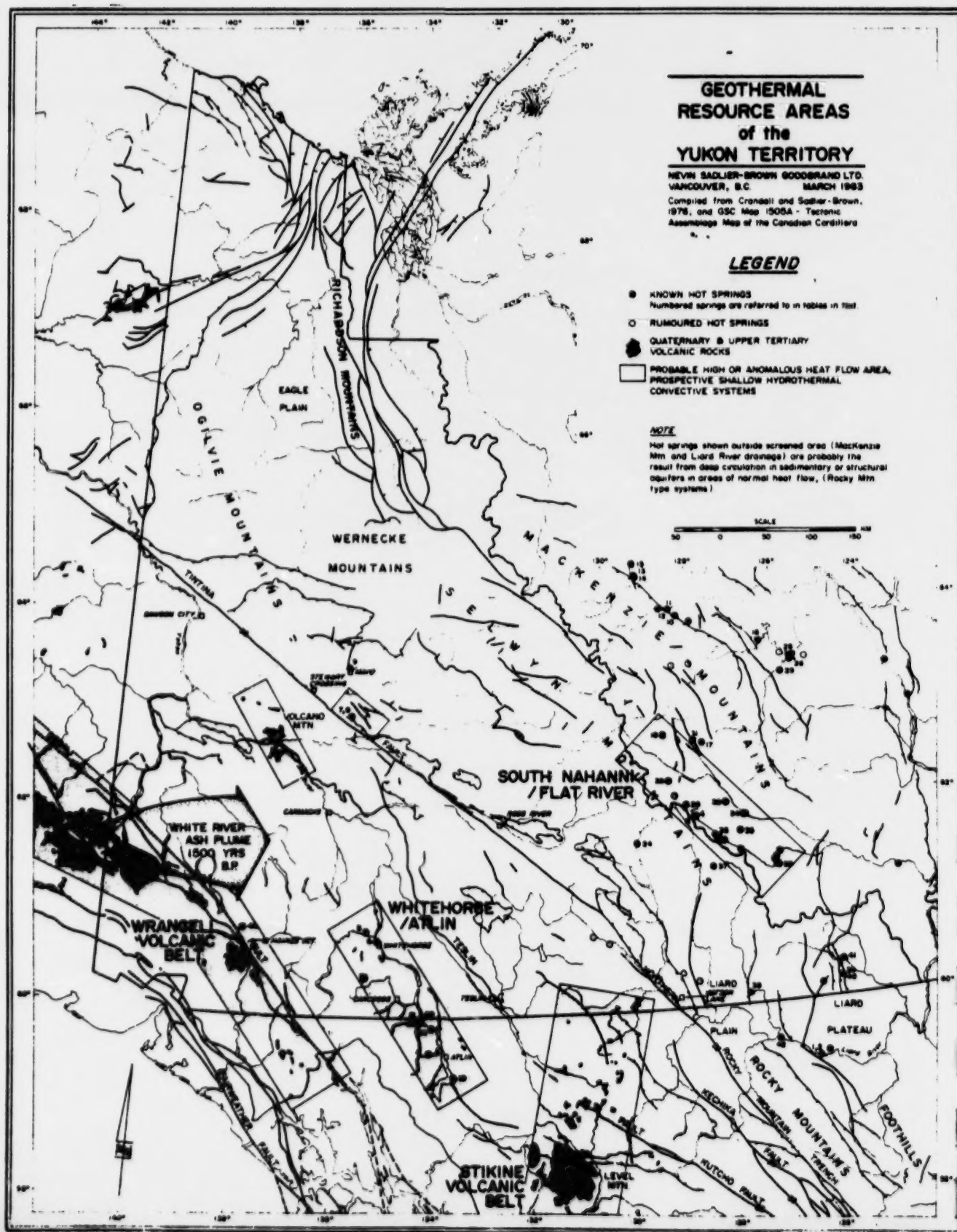
(c) Magnitude and Location of Geothermal Resources

Figure I.6 shows geothermal resource areas of Yukon, compiled for this study, from existing information. The shaded areas of probable high or anomalous heat flow and prospective shallow hydrothermal convective systems are based on a subjective interpretation of regional geology, the spacial distribution of young (Quaternary and Upper Tertiary) volcanic rocks and hot springs.

Hot springs are a surface manifestation of subsurface hydrothermal systems. Table I.7 summarizes basic data on thermal springs examined by Crandall and Sadlier-Brown⁽¹⁾. The reference numbers in the Table correspond to identifier numbers of springs on Figure I.6.

(1) Crandall and Sadlier-Brown, op. cit.

FIGURE I.6



Hot springs within the shaded area of Figure I.6 originate from hydrothermal systems within fractured metamorphic or intrusive rocks in areas of interpreted high heat flow. This system will mainly be low or moderate temperature systems ($<120^{\circ}\text{C}$) possibly suitable for direct use geothermal applications. One hot spring in Yukon and two in adjacent NWT, namely the MacArthur (7.8), Nahanni Headwater (18) and Nahanni North (30) springs, have subsurface temperatures of $\pm 100^{\circ}\text{C}$ based on thermal water chemistry at surface.⁽¹⁾

Direct use of geothermal energy for space and process heating is dependent upon proximity of the geothermal source to users. The geothermal system must be within 0.5-15km of the utilization site, depending on the scale of the intended application. As indicated in Figure I.6, several population centres and developing areas occur within areas containing potential shallow moderate temperature geothermal resources. These include Haines Junction, Whitehorse-Takhini, Atlin, MacMillan Pass, Howard's Pass and Tungsten areas. The overall potential of any of these areas depends, in part, on the energy capacity of potential applications as well as the magnitude of resources. The magnitude of the resource may exceed the total base load heat requirements in some instances. The magnitude and subsurface temperature of shallow hydrothermal systems is unknown at present and can only be determined with further site-specific exploration.

(1) Crandall and Sadlier-Brown, op. cit.

TABLE 1.7

Basic Data on Geothermal Springs

Reference Number	Name of Spring	MTS Map Sheet	Latitude	Longitude	Estimated Discharge (litres/sec)	Maximum Temperature (°C) At Surface	
					Total System	Spring Sampled	
1	Liard 1.	95M Rabbit R	59°25'	126°05'	+ 70	30	21
2	Liard 2.	95M Rabbit R	59 25	126 05		40	54
3	West Cantung	105M Frances L	61 55	128 15		<1	41
4	East Cantung	105M Frances L	61 55	128 15	30	steep	29
5	Tablini	105D Whitehorse	60 51	135 22	15	4	47
6	Verajice	105D Whitehorse	60 46	135 09	<1	<1	12.5
7	McArthur	105M Mayo	63 04	135 42	30	5	54.5
8	McArthur	105M Mayo	63 04	135 42	5	5	50
9	Mayo	205M Mayo	63 36	135 53	30	10	15
10	Elval	106A Mc. Edunt	64 03	128 15	30	5	15
11	Deca East	106A Mc. Edunt	64 10	128 25	7	10	46
12	Deca West	106A Mc. Edunt	64 10	128 25	<2	7	22
13	Mountain 1	106A Mc. Edunt	64 32	129 15	<2	8	16
14	Mountain 2	106A Mc. Edunt	64 31	129 15	15	15	10
15	Mountain 3	106A Mc. Edunt	64 31	129 15	<3	8	10
16	North Redstone	95M Wrigley L	64 38	129 13	25	steep	8.5
17	Grizzly Bear	95L Grigley L	63 43	126 25	30	20	9
18	Nahanni Headwater	1051 Nahanni	62 40	127 55	<1	steep	9
19	Atlin	104M Atlin	62 49	128 50	60	20	44
20	North North	104M Skapay	59 24	133 35	45	20	64
21	North Middle	104M Skapay	59 59	134 13	25	25	29
22	James L	104M Skapay	59 58	134 13	20	steep	9.5
23	North South	104M Atlin	59 53	134 00	45	45	15
24	McPherson L	105M Frances L	59 58	134 13	20	steep	13
25	South Redstone	95M Frances L	61 52	129 37	20	steep	17
26	Redstone Jct 1	95M Nahdint	61 52	129 37	20	steep	16
27	Redstone Jct 2	95M Nahdint	63 24	125 52	120	15	54
28	Redstone River water	95M Nahdint	63 32	125 42	25	28	15
29	North Cantung	95M Nahdint	63 33	125 44	4	2	5
30	Nahanni North	1051 Nahanni	63 33	125 44	5	steep	8
31	Nahanni North	1051 Nahanni	62 07	128 25	32	steep	32
32	Broken Skull	1051 Nahanni	62 22	128 08	40	15	58
33	Grigley L	95L Grigley L	62 45	128 08	35	25	45
34	Wild Mt	95E Flat R	62 05	127 35	25	25	3
35	Rabotkettle	95E Flat R	61 25	126 35	50	30	29
36	Mole-in-the-Wall	95E Flat R	61 57	127 11	<2	steep	21
37	Flat Fruit	95E Flat R	61 42	127 11	<2	steep	47
38	Cassat L	95E Flat R	61 40	127 35	30	10	11
39	Coal R	95D Coal R	61 25	127 52	40	steep	47
40	Larsen North	95D Coal R	60 08	127 25	40	40	3
41	Larsen South	95C La Biche R	60 12	125 30	45	45	13
42	Pool Cr	95C La Biche R	60 12	125 30	40	40	53
43	Portage Bruie	95C La Biche R	60 23	125 32	30	20	43
	Jarvic Cr	94M Rabbit R	59 38	126 57	3	3	54.5
		115A Dzadash	60 54	137 57	15	steep	48
					5	<1	16

Source: (Crandall) and Sedler-Brown, op. cit.

The potential of Watson Lake, Mayo and other areas where warm water may be present in local river basins is unknown. It is not expected that deep circulating Rocky Mountain Type systems will be a significant resource in the Yukon because of the nature of the low-grade heat source and the remoteness of potential systems.

Hot springs indicating high-temperature convective systems suitable for electrical power generation in or near areas of Quaternary volcanic activity are unknown in Yukon. Potential sites that either have no associated hot springs activity or where hot springs remain undiscovered will be confined to the Wrangell Volcanic Belt,⁽¹⁾ the Whitehorse region⁽²⁾ and the Volcano Mountain area (Crandall and Sadlier-Brown, 1976).

The existence of high temperature convective systems, their magnitude and temperature is undetermined at the present time. Individual systems, if discovered, may supply between 2MW-200MW of electrical power.

(d) Breakdown of Geothermal Resources

Geothermal resources classification systems are analagous to classification breakdowns in the mineral or oil and gas industries. No "proven" or "probable" geothermal reserves are known in the Yukon. All resources are either undiscovered or "possible" reserves.

(1) Souther, op. cit.

(2) Nevin Sadlier-Brown Goodbrand Ltd., A Proposal for a Preliminary Exploration Program for a Geothermal Resource in the Yukon Territory, (unpublished), 1982.

2.7 Hydrogen

(a) Description

Hydrogen is fast becoming recognized as an important potential fuel source in Canada. As an energy currency, hydrogen can be used in a gaseous state for small-scale residential space and water heating or for large scale industrial process heat. In addition, in its liquid state, hydrogen is highly transportable and can be used as motor vehicle and aviation fuel. Since these two end uses -- heating and transportation -- currently constitute the majority of oil and gas consumption, hydrogen offers a technically viable means for reducing dependence on hydrocarbons, although the infrastructure does not yet exist for utilizing hydrogen extensively.

A number of reasons exist for the appeal of hydrogen. First, it is a perfectly clean fuel in that, once "burned", its only by-product is water. Second, it is felt that the methods of storing and transporting the fuel are readily developed and are no less difficult than those encountered when handling hydrocarbon fuels. For example, it has been suggested that gaseous hydrogen could be immediately introduced into a natural gas pipeline system, on the basis of 10% volume, with no ill effects on the system and with little incremental investment. Third, substantial experience with hydrogen production at a large scale has already existed for decades in the oil refining and petrochemical industries.

Finally, the most appealing attribute of hydrogen is its abundance. Hydrogen is the most abundant element found on earth. Although very little elemental hydrogen exists, the resource base is vast since its primary occurrence is in the form of water. Also, hydrogen can be derived from any hydrocarbon such as coal, gas, or oil. The problems, of course, lie in constraints on the availability of processing inputs and in freeing the hydrogen from its original state in water or as a hydrocarbon. A number of technically viable methods exist for achieving this, although only two general types of processes are likely to become commercial at large scales.

The most commonly used process in Canada uses steam reformation or partial oxidation of hydrocarbons. This process essentially "burns" the hydrocarbons (methane or oil) in a wet medium to hinder oxidation and, when carefully controlled, gaseous hydrogen will form as a by-product. Of the hydrogen produced in Canada today, 76% is through methane reformation and 23% from liquid petroleum reformation. These processes are used mainly in the petroleum refining industry where hydrogen is required for upgrading.

The second commercially viable process is through water electrolysis. Although it accounts for only 1% of the hydrogen produced in Canada today, it has a relative advantage because of our abundance of electric energy potential and of the declining hydrocarbon resources. Water electrolysis involves the liberation of hydrogen by passing an electrical current through a solution of water and catalyst.

(b) Method of Inventory Measurement and Data Sources

As suggested above, hydrogen is a resource that is constrained, in potential, more by the availability of processing inputs rather than by the availability of the hydrogen itself. Water, for example, is so abundant that the resource base is effectively infinite. Electrolytic hydrogen, however, will certainly be constrained by the availability of electrical energy. Similarly, through reformation or other techniques, most of the hydrogen in Yukon's oil, gas and coal reserves could theoretically be tapped. No estimates of the hydrogen content in this hydrocarbon resource base are readily available. However, it is unlikely that petroleum refining of any significant scale would be established in the Yukon in the foreseeable future and it is likely that recovery of hydrogen from coal directly through reformation or indirectly through thermal based electrolysis would be inefficient and costly. For practical purposes, therefore, our preliminary estimates of Yukon hydrogen resources are based on electrolytic hydrogen, based on hydro-electric power.

The availability of electrical energy for producing hydrogen can be estimated as the total hydro-electric potential in Yukon minus requirements for direct use in residential, commercial and industrial sectors. At this stage the only available estimate of overall hydro-electrical energy potential in Yukon is in Monenco's paper presented at the Northern Development Conference of 1976.⁽¹⁾ Conversion factors for the electrolytic process and the energy content of hydrogen are presented below, based on the following sources:

(1) W.J. Smith, op. cit.

- (i) CERI, Study #16, Alternative Transportation Fuels in Canada, July, 1983.
- (ii) Committee on Alternative Energy and Oil Substitution, Energy Alternatives, Substitution, Ottawa, 1981.
- (iii) Ontario Hydro Energy Task Force, Hydrogen: A Challenging Opportunity, 1981.

Electricity demand forecasts for the Yukon are available from Hildebrandt-Young's 1982 study for NCPC.⁽¹⁾

(c) Magnitude and Location of Hydrogen Resource

Hydrogen is stored and used in different forms and, therefore, there are some ambiguities in methods of measurement. Volumetric methods are often meaningful when comparing densities for those of gas or oil, but they are cumbersome when referring to different end uses which depend on hydrogen being in a liquid or gaseous state. For this reason, we prefer to express hydrogen resources in terms of "tonnes of hydrogen" which can be readily converted to an energy equivalent in gigajoules. Based on the above information sources, 1 MW of electricity can produce 0.4 tonnes/day of hydrogen or 146 tonnes/year. This represents an energy content of about 60 GJ/day or 22,046 GJ/year.

(1) Hildebrandt-Young & Associates Ltd., Update: Market Forecast, Electrical Energy Requirements in Yukon, April, 1982. Note that this forecast applies only to NCPC's system, although this accounts for most of the load in Yukon. The "High" demand forecast is assumed here in order to generate a conservative estimate of electrolytic hydrogen potential.

Based on forecast electrical energy demand of about 2.7 million GJ by the year 2001-2002, an energy potential of some 208 million GJ and the above conversion factors, the total energy equivalent of electrolytic hydrogen in Yukon could reach some 145 million GJ per year.

2.8 Wind

(a) Description

The most common utilization of wind as an energy source in Canada is small capacity (200 W to 2 kW) windmills which generate electricity for such uses as refrigeration, lighting and the operation of small appliances in remote areas with no access to an interconnected grid. Larger windmills can provide the full electrical load for a home or community or feed into a grid. Normally, because of fluctuations in wind energy over time stand-by sources such as a diesel generator, storage battery or grid are required. The effects of varying wind speed are compounded by the fact that wind power is a function of the cube of wind speed. The alternative to stand-by resources is to utilize wind energy in applications that are inherently capable of accepting a variable energy input.

(b) Method of Inventory Measurement and Data Sources

It is impossible to meaningfully define and estimate the total energy potential which can be derived from wind in Yukon. Theoretically, energy potential would be limited only by the number and size of machines which could be placed on available land. However, average wind speeds vary greatly from one location to another depending on such factors as topography, tree cover and climatology. The approach taken here will be to describe the characteristics which determine the electrical energy potential and feasibility at any given site, to present available information on these characteristics for

various sites in Yukon and to estimate the average energy output per m^2 rotor area for sites characterized by different average wind speeds. On this basis, the most promising areas in Yukon for utilization of the wind resource can be discussed. Unfortunately, the small number of sites for which data is available and the marked variation of topographic features make generalizations very difficult.

There are a number of factors which affect the electrical energy potential from a given wind generation site. The most important are, of course, the average wind speed and the frequency with which certain wind speeds are attained. Wind speed and frequency determine the capacity factor at a particular site. Prevailing wind direction is more important in site selection than as a factor determining power potential. In order to translate information collected at measuring sites into data appropriate for assessing wind generation sites, correction factors for site exposure and anemometer height differences must also be applied.

Data on mean monthly and annual wind speed direction and frequency of direction dating as far back as 1955 are available for 14 sites in Yukon from the Atmospheric Environment Service.⁽¹⁾ Also available from the Alberta Research Council are detailed wind speed, frequency and energy estimates which they developed for four sites in Yukon, including Whitehorse, Watson Lake, Dawson and Burwash for the 1967-76 period.⁽²⁾ Detailed wind speed and frequency data are

(1) AES, Canadian Climate Normals, Volume 5, Wind, 1951-80.

(2) Solar and Wind Energy Research Program (SWERP), Alberta Research Council.

also available for 2 demonstration locations (Destruction Bay, Old Crow) which were established under the Canada-Yukon CREDA to provide base information for determining the feasibility of wind power in Yukon. However, this information has been compiled only for a 1 or 2 year period to date.

(c) Magnitude and Location of Wind Resource

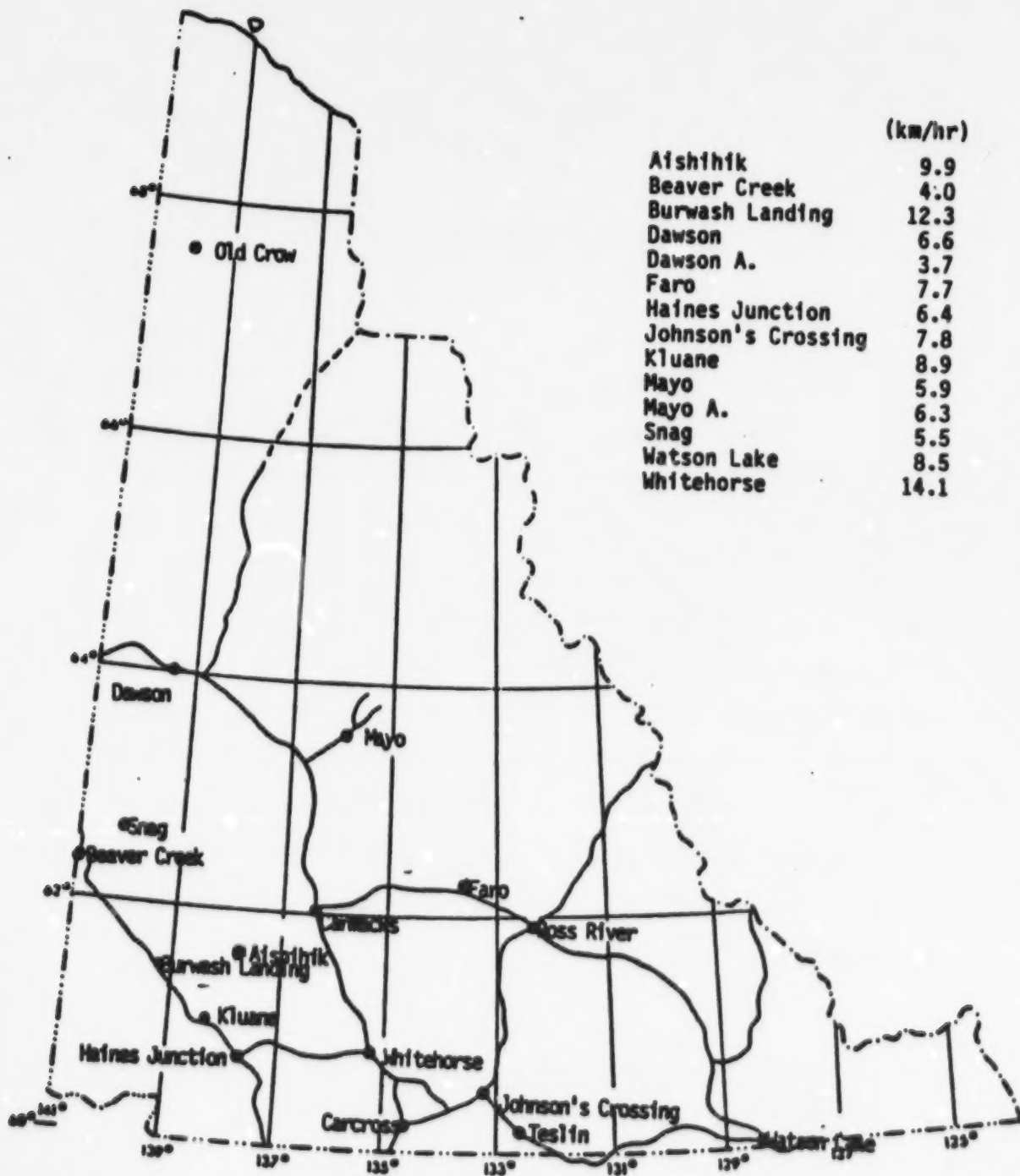
Wind speed and frequency data are summarized below in Table I.8, along with the location and description of the measuring station, the station elevation anemometer height and period of measurement. Figure I.7 shows the location of wind measurement stations in Yukon.

Only three sites have average annual wind speeds of about 10 km/hr or over: Aishihik, Whitehorse and Burwash Landing. Even these average wind speeds are at the lower end of the range that is usually considered suitable for small scale wind power generation in southern Canada, except for very special applications where cost is not the primary consideration.⁽¹⁾ However, it should be noted that stations and anemometers are not placed with the objective of attaining optimum wind generator conditions.

(1) E.J. Wiggins, Prospects for Solar and Wind Energy Utilization in Alberta.

FIGURE I.7

Wind Speeds at Measuring Sites in Yukon



Wind frequency data compiled by the Alberta Research Council are presented in Table I.9 for four sites in Yukon. This Table shows the percentage of time when wind speeds were greater than various levels (v) throughout the 1967-76 analysis period.

There are too few existing measurement stations and topographical features sites so varied among sites to draw any firm conclusion about areas in Yukon with the best potential for wind. The highest average wind speeds seem to occur in southwest Yukon locations exposed to southerly winds. Average wind speeds tend to drop off during winter months at most locations, although this variation is not likely to be as great in terms of energy availability as in the case of solar. Note also that the average wind speed decline is less significant for the southwest Yukon sites.

TABLE 1.8

Mean Monthly and Annual Wind Speed (km/hr) and Prevailing Direction

Station	Period of Record	Station Elevation	Anemometer Elevation	Mean Wind Speed and Prevailing Direction											
				Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec. Ann.
Aishihik A.	1955-80	966	11.3	5.8 S	8.3 S	8.9 S	10.9 S	14.0 S	12.1 S	11.4 S	10.8 S	10.6 S	11.1 S	8.6 NNE	9.9 S
Beaver Creek	1969-80	663	10.1	1.9 S	2.6 S	4.1 S	5.6 NW	6.2 NW	5.8 NW	4.9 NW	4.7 NW	4.4 NW	3.5 NW	2.4 S	1.8 NW
Burnah A.	1966-80	799	10.1	7.1 NW	10.5 NW	10.3 NW	15.5 ESE	16.2 ESE	13.7 ESE	12.6 ESE	12.5 ESE	14.4 SE	15.2 NW	11.4 NW	8.5 ESE
Dawson	1955-80	320	13.4	5.2 SW	7.0 SW	7.2 SW	8.4 N	7.6 SW	6.5 SW	5.9 SW	5.5 SW	5.8 SW	8.1 N	6.4 SW	6.1 SW
Dawson A.	1976-80	369	11.0	1.5 ENE	1.7 SW	3.6 E	5.9 E	6.8 E	5.4 WSW	4.1 SW	4.2 E	4.3 ENE	3.2 E	2.0 ENE	2.0 E
Faro	1972-80	694	10.1	5.2 SE	6.2 SE	7.9 SE	9.2 SE	9.8 SE	9.8 SE	9.3 NW	7.6 NW	7.7 SE	8.0 SE	6.1 SE	5.4 SE
Malnes Junction	1963-80	599	10.1	4.1 NE	5.5 NE	6.3 NW	7.8 NW	9.2 NW	9.3 SW	7.7 NW	6.7 NW	5.6 NW	5.2 NE	4.7 NE	4.2 NE
Kluane Lake	1974-80	766	10.1	6.0 SE	7.8 SW	8.4 SW	9.6 SW	9.3 SW	8.9 SW	8.2 SW	9.4 E	9.9 E	9.9 SE	11.0 SE	8.9 SW
Mayo	1955-80	504	10.1	2.6 N	5.8 NE	7.5 NE	8.6 NE	7.9 NE	6.6 SW	5.4 SW	5.0 NE	6.1 NE	7.1 NE	4.4 NE	4.0 NE
Mayo A	1963-80	504	10.1	4.0 N	6.0 N	8.8 N	8.8 N	7.8 N	5.7 N	4.3 N	4.3 N	6.1 N	9.7 N	5.2 NNE	4.5 N
Snag A	1955-80	587	10.1	2.2 E	3.8 E	5.7 NW	7.4 NW	8.3 NW	7.8 NW	6.7 NW	6.2 E	6.3 NW	5.8 NW	3.7 NW	2.6 NW
Testin A	1955-80	705	10.1	5.2 E	6.3 E	7.1 E	8.2 S	8.9 S	8.9 S	8.7 S	7.9 S	7.8 NE	9.3 NE	8.9 ENE	6.6 E
Watson Lake A.	1955-80	609	10.1	3.9 NW	5.5 W	8.6 ESE	10.9 ESE	11.4 W	11.4 W	10.5 W	9.6 W	9.7 ESE	10.1 ESE	5.8 NW	4.1 NW
Whitehorse A	1955-80	703	10.1	12.9 SSE	14.9 SSE	14.3 SSE	14.3 SE	14.4 SE	12.8 SE	12.4 SE	12.4 SE	13.8 SSE	16.4 SSE	15.7 S	14.5 SSE

TABLE I.9
Wind Frequency for Selected Yukon Locations (1967-76)
(%)^a

Wind Speed (v)	Location			
	Whitehorse	Dawson	Watson Lake	Burwash
5	74.1	50.4	47.6	62.7
10	56.7	20.3	26.9	46.0
15	39.5	11.4	15.9	33.9
20	24.4	4.9	9.0	22.1
25	11.6	2.5	4.0	13.0
30	4.1	0.7	1.5	6.6
35	1.1	0.1	0.4	3.1
40	0.4	0.0	0.1	1.6
45	0.1	0.0	0.0	0.8
50	0.0	0.0	0.0	0.4
55	0.0	0.0	0.0	0.2
60	0.0	0.0	0.0	0.1
Average Wind Speed (km/hr)	13.0	6.8	7.5	11.6

(a) Percent of time when wind speeds greater than v.

The amount of energy that is theoretically available on average from a wind stream and a given wind mill is approximated by the so-called power equation:

$$P = 1/2 d A V_w^3$$

where: P = power

d = air density

A = area swept by rotor

V_w = average velocity of the wind

Air density will vary with temperature, elevation and air pressure. The maximum proportion of the power in a windstream that can be extracted by a windmill rotor is given by the so-called Betz coefficient. The theoretical maximum for this coefficient is .5926. Actual coefficients for windmills available currently will be much less than this by varying degrees depending on the design type. Assuming a Betz coefficient of .5926 and a constant value for d (represented in the equation by the letter K), the power equation can now be written:

$$P = .5926 K A V_w^3$$

The Alberta Research Council⁽¹⁾ has estimated wind energy in MJ per m² of rotor area by month for four sites in Yukon, Whitehorse, Dawson, Watson Lake and Burwash over the 1967-76 period. This data, summarized by month below in Table I.10, represents the maximum amount of energy which can be derived from a wind stream within a given area (i.e. based on Betz coefficient of .5926).

(1) SWERP, op. cit.

TABLE I.10

Mean Wind Energy From All Directions by Month 1967-76: Selected Yukon Locations

(MJ/m² of rotor area)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Whitehorse	126.9	174.8	124.2	116.0	112.7	74.5	69.7	72.7	115.6	143.9	174.4	157.0	1462.3
Dawson	25.7	56.8	45.3	58.3	63.4	20.1	18.4	16.9	21.4	47.5	30.0	35.5	412.4
Watson Lake	18.5	25.4	53.9	70.6	75.6	75.3	58.3	47.2	58.7	62.1	18.3	12.8	576.7
Burwash	63.8	129.2	102.6	225.5	218.4	126.3	109.7	115.7	164.6	184.4	153.7	140.1	1734.8

2.9 Solar

(a) Description

Solar energy is most commonly captured by collectors of various types for space and water heating and less commonly for direct conversion to electricity (photovoltaics). As with wind, the amount of solar energy potentially available is very large. It can be produced anywhere instead of at specific sites as with most other fuels and thus distribution costs are negligible or zero. However, because of solar's very low "energy density", relatively large installations with correspondingly large capital costs are needed to produce significant amounts of energy. Another major problem with solar energy in high latitudes is the very low radiation levels occurring at the time when heating loads are highest. This necessitates the tilting of collectors at a higher angle, the provision of storage capacity, the use of solar energy in inherently variable applications or an increase in collection capacity relative to the required load. Even with these measures, it is generally necessary to complement solar energy with conventional fuels.

Current utilization of solar energy in Yukon is primarily limited to private use in the residential sector. Several demonstration projects have been funded through the Canada-Yukon CREDA including photovoltaic, hot water and greenhouse space heating applications.

(b) Method of Inventory Measurement and Data Sources

The amount of solar energy potentially available in most areas is very large, as with wind. For example, it has been estimated that the total amount of solar energy falling on Alberta is over 500 times the present production of energy in that province in all forms, including exported energy.

The intensity of solar energy reaching a particular point on the earth's surface is controlled by the latitude, time of day and year and the amount of atmospheric absorption and scattering due to clouds, dust and water vapor. These variations in solar radiation intensity generally follow normal daily and annual cycles, particularly at higher latitudes.

The basic data which is commonly used to define the availability of solar energy in Yukon is hourly horizontal surface solar radiation data.

Horizontal solar radiation or radiation falling on a horizontal surface is measured by the AES in four different ways known as Radiation Fields. The fields used by the AES are defined below.

Radiation Field	Description
RF1	Global Solar Radiation: the total incoming direct and diffuse short-wave solar radiation received from the whole dome of the sky on a horizontal surface.
RF2	Sky Radiation (Diffuse): the portion of the total incoming short-wave solar radiation received on a horizontal surface that is shielded from the direct rays of the sun by means of a shade ring.
RF3	Reflected Solar Radiation: the portion of the total incoming short-wave radiation that has been reflected from the Earth's surface and diffused by the atmospheric layer between the ground and the point of observation onto a horizontal surface.
RF4	Net Radiation: the result of downward and upward total (solar, terrestrial surface, and atmospheric) radiation received on a horizontal surface.

For purposes of resource description the most useful measure is RF1 or global solar radiation. Unfortunately solar radiation data is not collected for a large number of sites in Canada, and in Yukon, only at Whitehorse. This data, provided by the Atmospheric Environment Service⁽¹⁾ for the years 1967-76 is summarized below in Table I.11.

Bright sunshine data which is available for four locations in Yukon⁽²⁾ can also be used to calculate horizontal surface solar radiation.⁽³⁾ This data is presented in Table I.12.

(1) Atmospheric Environment Service, Canadian Climate Centre, Ontario.

(2) AES, Canadian Climate Normals, Volume 7, Bright Sunshine, 1951-80.

(3) Based on a methodology developed by J.E. Hay, Calculation of Monthly Mean Solar Radiation for Horizontal and Inclined Surfaces, 1979.

(c) Magnitude and Location of Solar Resource

Assuming a uniform distribution of solar radiation, the total amount of solar energy theoretically available in Yukon can be estimated at 1,747,000 million GJ.⁽¹⁾ A more useful perspective on the magnitude of solar energy resource is the quantity of useable energy that can be produced per unit area of collector. This will be influenced by the performance, slope and orientation of the collector and local meteorological conditions, but for a horizontal collector of one square metre in area in Whitehorse the average amount of global energy intercepted over a year is about 3,620 MJ. This is likely to be roughly representative of locations throughout southern Yukon. For the same collector inclined at 60°⁽²⁾ and facing south, the annual energy intercepted would be in the order of 4,625 MJ.

(d) Breakdown of the Solar Resource

Because of the relatively uniform nature of solar energy it can be produced almost anywhere in the southern half of Yukon with approximately the same degree of efficiency. Solar intensity and seasonal imbalance will be more marked in northern Yukon. However, Inuvik, which should be representative of locations in the far north of Yukon, receives only slightly less global solar radiation on a mean daily basis than Whitehorse.⁽³⁾

(1) This estimate is based on average global solar radiation for Whitehorse over the 1967-76 period at 3,620 MJ/m².

(2) Optimal incline is roughly estimated as latitude plus 15°, or about 70° for Whitehorse.

(3) AES, op. cit.

TABLE I.11

Mean Daily Global Solar Radiation on Horizontal and Sloped Surfaces:
Whitehorse 1967-76

(MJ/m²)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Horizontal Surface	1.3	4.0	9.4	15.0	19.3	20.8	18.4	14.6	8.8	4.4	1.7	0.7	9.9
Sloped ^a Surface	6.0	11.3	16.6	18.1	18.4	17.9	16.6	15.6	12.3	9.3	5.8	3.9	12.8

(a) South facing, 60°.

Source: AES, Canadian Climate Centre, op. cit.

TABLE 1.12
Total Bright Sunshine
 (hours)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Fort Selkirk	7.5	91.2	168.2	229.7	281.8	280.0	268.0	246.8	142.9	79.7	16.4	7.7	1819.9
Haines Junction	19.3	78.0	161.4	220.7	282.8	275.7	275.4	235.9	139.8	91.5	24.4	1.7	1806.6
Watson Lake A.	45.1	85.3	134.8	216.6	255.2	265.0	262.6	228.0	126.5	95.6	42.9	31.3	1788.9
Whitehorse A.	46.0	91.0	153.1	229.5	259.2	272.8	250.2	230.7	136.5	93.4	58.3	23.0	1843.8

Source: AES, Canadian Climate Normals.

II. ENERGY UTILIZATION REVIEW

1.0 INTRODUCTION

The purpose of this component of the study is to identify and assess the relative costs, limitations and advantages of the full range of energy sources which can be used presently or in the future to meet Yukon's energy requirements.

As directed in the terms of reference, the assessments rely exclusively on existing data and literature sources, available both within and outside Yukon. A wide range of information sources have been used and they are noted in the relevant sections in the text.

The energy utilization review is separated into two parts. In Section 2, costs and other aspects of using alternative sources are analyzed on a source by source basis. For each energy source there is an introductory discussion of existing and potential sources and uses, followed by a cost and then other factor assessment. In the cost assessment, a distinction is made (whenever possible) between the fuel cost (on an input GJ basis) and the cost of utilizing the fuel in specific applications (on an output GJ basis, taking combustion efficiencies and user equipment costs into account).

In Section 3, costs of using alternative sources are organized on a sectoral basis. For each sector a list of relevant sources are compiled. Then, relying on the source-by-source assessments, the relative merits of the different sources in each sector are identified and discussed. Section 3 provides in effect a summary of the energy utilization review.

Before proceeding to the analysis, it should be emphasized that in a review of this nature, which covers such a wide range of sources and applications, the cost estimates must be recognized as rough. This is satisfactory for the purpose here, which is to identify potentially attractive energy sources and 'order of magnitude' comparisons. However, much more research would be required to derive more precise estimates.

It should also be noted that the method by which the diverse sources, with their markedly different cost characteristics, have been assessed on a comparable cost basis is to calculate the average levelized cost associated with their use. Average levelized cost refers to the constant real cost per unit of energy output, which if multiplied by the energy output each year over the life of an energy-using or producing facility, would in present value terms be equivalent to the actual time pattern of costs associated with it. It is calculated by dividing the present value of total lifetime costs by

the present value of lifetime energy output.⁽¹⁾ Consistent with current EMR practice, a discount rate of 7% real is used for a calculations.

(1) In general, the levelized cost equation is as follows:

$$l = \frac{\sum_{i=1}^n \frac{K_i + O_i}{(1+r)^i} + \sum_{i=1}^n \frac{F_i/\alpha}{(1+r)^i}}{\sum_{i=1}^n \frac{E_i}{(1+r)^i}}$$

Where

- l - average levelized cost
- K_i - equipment capital expenditures, year i
- O_i - equipment operation expenditures, year i
- F_i - fuel cost per input gigajoule, year i
- α - fuel combustion efficiency
- E_i - output energy production or requirement
- n - equipment life expectancy
- r - discount rate

2.0 ANALYSIS BY ENERGY SOURCE

Currently, Yukon energy requirements are met largely by refined petroleum products. Electricity, propane and wood are also important sources of energy supply. There are, however, a wide range of energy sources which could potentially be used in Yukon. Sources which are currently used on either a limited or demonstration- level basis include coal, wind, solar, geothermal, and waste diesel. Other significant sources which might be considered or available in the future include natural gas, peat, municipal waste, and hydrogen.

Each of these existing or potential energy sources are analyzed in this section.

2.1 Refined Petroleum Products

(a) Existing Sources and Uses

Refined petroleum products are brought into Yukon by truck over the Alaska Highway and by barge from Vancouver to Skagway or Haines and from there by truck or pipeline to Whitehorse.⁽¹⁾ These products, which currently account for an estimated 80% of total Yukon energy demand, are used for heating, transportation and electric power generation. The contribution of RPP's to energy demand by sector as estimated by Hodge⁽²⁾ is summarized below. These estimates demonstrate Yukon's heavy dependence upon RPP's for its energy needs.

<u>Sector</u>	<u>RPP's Share of Total Sectoral Demand</u>	<u>Major End Uses</u>
Residential	56%	Space and water heating
Commercial	80%	Heating and cooling
Industrial	56%	Process heat
Electric Power Industry	15%	Diesel generation
Transportation	100%	Auto, truck, air

(1) There is a small diameter (4") pipeline running from Skagway to Whitehorse.

(2) R.A. Hodge, Northern Energy: A Soft Path Analysis of the Yukon and Northwest Territories, October, 1982.

(b) Potential Sources and Uses

Other than the conventional supply sources from southern Canada, the potential supply sources for petroleum products are:

(i) Oil products produced from the refining of oil supplied by a major pipeline delivering Beaufort area oil to southern markets. Two obvious choices for the pipeline route are down the Mackenzie Valley and along the Dempster highway. A Mackenzie Valley pipeline would connect with the Alberta pipeline system for eventual delivery to Montreal. A Dempster highway pipeline would either connect with the Alaska oil pipeline or an ocean terminal at Haines or Skagway. A small refinery referred to as a topping plant could be built to process the relatively small amounts of oil required in Yukon.

(ii) The purchase of oil products from a topping plant located in the Beaufort Sea - Mackenzie Delta area assuming a transportation system for delivery of oil to southern markets is not in place. Oil companies in the Beaufort area are considering the construction of a topping plant to serve the fuel needs of exploration activity in the area. Presumably Yukon could purchase product from such a plant. The product would be trucked along the Dempster highway to Whitehorse.

(iii) The purchase of refined products from Alaska. There is a refinery at North Pole, Alaska from which petroleum products might be purchased. In addition there is a topping plant at Delta Junction, which takes oil from the Alaska oil pipeline for processing. Of the products produced, the diesel is used to fuel a pipeline compression station located at Delta Junction. The remaining products are for the most part put back into the pipeline.

(iv) Finally there is the potential of oil production in Yukon. Of the fields in Yukon that have been identified as potential sources of oil and/or gas, the Eagle Plains field is probably the most promising at this time. There have been oil indications in this field though not of commercial quantity.

In terms of potential uses, given its versatility, oil could conceivably, either directly or indirectly through the production of electricity, meet most of Yukon's energy requirements. This is the advantage of oil, but given its source and high cost, it is at the same time the major energy policy problem facing Yukon.

(c) Cost Analysis

Fuel Cost - Existing Sources:- Refined petroleum product energy costs on a per output GJ basis depend on the delivered prices of each product form, their energy content and their combustion efficiency. Average levelized or life cycle costs in specific applications depend as well on combustion equipment costs and economic life.

Delivered (retail) prices for selected refined petroleum products currently prevailing in various Yukon communities are shown in Table II.1. Costs per litre have been adjusted to costs per input GJ on the basis of an average energy content of .039 GJ/litre.⁽¹⁾

TABLE II.1
Selected Refined Petroleum Product
Retail Prices^d
(\$1983/GJ)

	<u>Whitehorse</u>	<u>Dawson City</u>	<u>Watson Lake</u>	<u>Faro</u>
Regular Gasoline	\$13.18	\$14.77	\$13.64	\$16.00
Diesel Fuel	\$13.28	n.a.	n.a.	n.a.
Heating Fuel (Regular)	\$10.35	\$11.64	\$10.04	\$10.94

(a) Source: Yukon Department of Tourism & Economic Deveopment, Fuel Price Survey, April 15, 1983. Estimates do not account for burning efficiencies in different uses.

(1) Energy, Mines & Resources, Conservation & Renewable Energy Branch.

While these prices reflect what consumers actually pay, because of road and other oil product excise taxes they do not reflect refined petroleum product costs from a Yukon point of view. In Table II.2, current refined petroleum product costs from an overall Yukon perspective are shown, with road and other product taxes netted out.

TABLE II.2

Selected Refined Petroleum Product
Retail Costs (Territorial Taxes
Netted Out)^a
(\$1983/GJ)

	<u>Whitehorse</u>	<u>Dawson City</u>	<u>Watson Lake</u>	<u>Faro</u>
Regular Gasoline	12.03	13.62	12.49	14.85
Diesel Fuel	12.12	n.a.	n.a.	n.a.
Heating Fuel (Regular)	10.31	11.59	9.99	10.87

(a) Source: Yukon Department of Tourism & Economic Development.
Based on road tax of 4.5¢/l. and heating tax of .2¢/l.

Future refined petroleum product prices will depend on many factors: trends in the world price of oil; future relationship between the Canadian blended and world oil price; refinery costs; refinery sources and delivery costs. It is beyond the scope of this study to examine these factors, many of which are very uncertain in any event. However, in light of most oil price forecasts currently available it does seem reasonable to assume some real increase in prices over the

long term. While real decreases may occur throughout part of this decade, a rising Canadian to world price ratio and a gradual diminishing of the world oil surplus capability should be sufficient to raise product prices in Canada generally and Yukon in particular. For purposes of this study we assume that costs of refined petroleum products from existing sources will rise at an average real rate of .5% per year over the long term.

Fuel Cost - Potential Sources:- As noted in section (b), oil products could be supplied in Yukon from a topping plant for northern crude oil. Such plants perform a relatively simple processing of oil as compared to a conventional refinery. The mix of product produced by the plant is heavily dependent on the quality of crude input. A relatively low quality crude with low API and high sulphur content will produce more of the heavier products such as residual fuel oil and asphalt and less of the lighter products such as gasoline and kerosene.

A 5000 barrel per day (b/d) topping plant would meet Yukon's requirements for diesel fuel, furnace oil, aviation fuel and motor gasoline.

The typical yield for a 5000 b/d topping plant processing 30° API crude with .2% sulphur is as follows:

	B/d
Naptha, gasoline & kerosene	2150.0
Diesel	1300.0
Fuel Oil	1462.5
Plant fuel	<u>87.5</u>
Total	5000.00

A topping plant could be located in Whitehorse or in the Beaufort. Table II.3 shows an estimate of product prices at Whitehorse in 1990 assuming a topping plant at Whitehorse on a Dempster highway pipeline system. The assumptions are listed in the notes to the table. According to these assumptions an average product price of about \$9.95/GJ (1983 \$) in 1990 would result from this scenario. This is significantly lower than the current cost of refined petroleum products.

Table II.4 shows the product price at Whitehorse assuming a Mackenzie Valley pipeline and a topping plant at the Beaufort. The product would be delivered by truck down the Dempster highway to Whitehorse. The average price at Whitehorse is about \$13.80/GJ (1983 \$), of which 30 percent or \$4.10/GJ is the product transportation charge between Beaufort and Whitehorse.

Other potential sources include imports from Alaska and refining of Yukon oil reserves. The cost of importing product from Alaska is likely to be similar to a topping plant in the Beaufort Sea because of the similarity in distance and transportation charges.

With respect to the development of oil reserves in Yukon, it is felt that this alternative will not materialize until a transportation system is in place for Beaufort-Mackenzie Delta oil. Since the most promising field, Eagle Plains is in the northern part of the Territory, the transportation charge will constitute a large portion of the delivered cost. Oil would have to be produced from the Eagle Plains field for about \$5.40 - \$5.65/GJ to be competitive with traditional supply prices. This assumes the truck transportation rate at about \$2.50/GJ.

The alternative of pipelining refined product from the different supply sources discussed above would be considerably more expensive than truck transportation. The small quantities involved would mean an extremely high pipeline tariff.

TABLE II.3

Product Price Estimate at Whitehorse
Assuming Dempster Highway Pipeline 1990
(1983 \$)

	<u>¢/l</u>	<u>\$/GJ</u>
Price of Crude Oil at Whitehorse ⁽¹⁾	20.4	5.23
Refining Cost ⁽²⁾	4.4	1.13
Marketing and Distribution ⁽³⁾	<u>14.0</u>	<u>3.59</u>
Average Product Price	38.8	9.95

Notes: (1) Crude oil costs at Whitehorse are based on a current world oil price of approximately \$36/bbl Canadian, escalating at an assumed .5%/yr. to 1990. A transportation charge of approximately \$5/bbl is assumed between Whitehorse and southern markets and is deducted from the world oil price to determine the crude oil price at Whitehorse.

(2) Based on discussions with industry personnel and oil product cost breakdowns from Petroleum Resources Communication Foundation.

(3) Excludes Yukon product taxes estimated to average 4¢/l.

TABLE II.4

Product Price Estimate at Whitehorse
Assuming Beaufort Topping Plant
(1983 \$)

	<u>¢/l</u>	<u>\$/GJ</u>
Price of Crude Oil at Beaufort ⁽¹⁾	19.4	4.97
Refining Cost ⁽²⁾	4.4	1.13
Truck Transportation to Whitehorse ⁽³⁾	16.0	4.10
Marketing and Distribution ⁽⁴⁾	<u>14.0</u>	<u>3.59</u>
Average Product Price	53.80	13.79

Notes: (1) Assumes market price of \$36/bbl escalating at .5%/yr. to 1990 and Beaufort to market transportation cost of \$6.90/bbl.

(2) Based on discussions with industry personnel and oil product cost breakdowns from Petroleum Resources Communication Foundation.

(3) Based on discussions with industry personnel.

(4) Excludes Yukon product taxes estimated to average 4¢/l.

Utilization Costs - Space Heating Application:- Based on existing sources, heating oil costs of approximately \$10.30 per input GJ, rising at a real rate of approximately .5%/yr. can be expected in the Whitehorse area. Costs in other Yukon communities will be higher. If an oil pipeline is constructed along the Dempster Highway and a topping plant constructed in Whitehorse, lower heating oil costs could result, but the future development of such a line and facility is far from certain.

In Table II.5, the average levelized cost of space heating with heating oil are shown, based on existing source costs. On the assumption of a combustion efficiency of 65%,⁽¹⁾ furnace costs of \$4000⁽²⁾ and a furnace life of 15 years, the average levelized cost is \$19.05 per output GJ.

(1) Stone and Webster Canada Ltd., Economic and Technical Feasibility Study of Distributing Natural Gas/Propane to Three Yukon Communities, Preliminary Draft, 1983.

(2) Ibid.

TABLE II.5

Average Levelized Cost
of Space Heating with
Light Fuel Oil

1983 Fuel Cost (\$/input GJ)	10.30
Escalation Rate (%/Yr.)	.5
Efficiency Factor	.65
Furnace Cost (\$)	4000
Furnace Life (Yrs.)	15
Average Annual Energy Output (GJ/household)	150
Average Levelized Cost per Output GJ \$19.05	

Notes: (1) Furnace cost life and efficiency factor from Stone & Webster Canada Ltd., op. cit.

(2) Average annual energy output based on average heating requirements for existing housing in Whitehorse estimated by Hildebrandt-Young, Projected Yukon Energy Requirements 1980-91, October 1981.

Utilization Costs - Diesel-Generated Electricity:- Based on existing sources diesel oil costs of approximately \$12.10 per input GJ can be expected in the Whitehorse area, rising at a real rate of .5%/yr. Again, higher costs in other Yukon communities can be expected.

In Table II.6, the costs of producing electricity with diesel-fired generators are shown based on NCPC estimates for a 2 x 1.5 MW unit plant. The Table indicates an average levelized cost of diesel-fired electricity of \$52.26/GJ. The costs are high not only because of the high price of diesel but also because of the low combustion efficiency and low load factor⁽¹⁾ assumptions. The low efficiency factor in particular is responsible for a large component of the difference between the input fuel and output electricity costs.

(1) Load factor refers to the ratio of actual annual demand over the total demand that could be met if the plant were operating at full capacity 24 hours per day, 365 days per year.

TABLE II.6
Average Levelized Cost
of Diesel-Generated
Electricity

1983 Diesel Fuel Cost (\$/input GJ)	12.10
Escalation Rate (%/Yr.)	.5
Efficiency Factor	.314
Plant Capital Costs (\$/Kw)	935
Plant Maintenance Costs (\$/GJ)	3.06
Plant Operating Costs (\$/Yr.)	55,000
Average Load Factor	.38
Plant Life (Yrs.)	15

Average Levelized Cost per Electricity Output in GJ	\$52.26
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Source: NCPC, Mayo System Economic Feasibility of Alternative Generation Strategies, 1982.

(d) Other Assessment Factors

Technical Constraints:- The distribution and use of refined petroleum products for heating, transportation and other applications is obviously well established in Yukon and elsewhere. In fact a major advantage of petroleum products is their flexibility in use and ready availability. For transportation, RPP's are currently the only fuel in widespread use.

Oil pipelines or development of oil reserves in Yukon may increase security but the extent to which this is the case will ultimately depend on the access Yukon has to these developments and Yukon's legal control over them.

With respect to electricity generation, the costs of diesel generation are very high. However, there are still certain advantages to diesel generation. Firstly, a diesel unit can be installed in a much shorter period of time than alternative sources of electricity, particularly hydro. Also, a diesel unit can be installed at the load centre, eliminating the requirements for expensive transmission facilities.

A diesel unit can be removed and sold. Diesel units can be installed in small units and additional capacity is easily attained by adding more units. In general, the flexibility of diesel generation is a positive factor supporting this type of generation. Also, the operation of diesel generators is very simple and does not require the full time attention of licensed personnel as do, for example, steam plants. This is a distinct advantage in remote communities.

To provide reliability with diesel generation, back up or standby generators are often provided. This particularly applies to remote communities not served by a transmission grid. This will increase the cost of energy, but the most important factor accounting for energy costs will continue to be the price of fuel.

The costs of diesel generation are subject to considerable variation as the price of diesel fuel varies. Such is not the case with hydro power which has a relatively high proportion of fixed to variable costs. For those economic activities such as mining where electricity costs can form a major component of overall costs, the decision to proceed with new developments requires not only relatively low energy costs but energy costs which are not subject to sharp and random fluctuations in the future.

Environmental and Economic Impacts:- Probably the most important environmental impact related to use of refined petroleum products including the generation of electricity, is air pollution from vehicles, refineries or diesel generating units. Oil field development or refinery and pipeline construction also can result in adverse land use impacts.

With respect to economic impacts, the construction of topping plants and pipelines or oil field development could result in significant construction-related employment and income but relatively small operating effects. It would nonetheless be a significant improvement over the current situation where virtually no economic spinoffs result from the use of refined petroleum products, except in distribution.

The installation of new diesel units provides very little economic activity for the Yukon Territory. There is relatively little on-site construction required. Most of the expenditures flow outside the Territory in the purchase of the generators.

2.2 Electricity

(a) Existing Sources and Uses

Next to refined petroleum products, electricity is the most widely used energy source in Yukon. Electricity's contribution to energy demand by sector and end use in Yukon is estimated by Hodge⁽¹⁾ as follows:

<u>Sector</u>	<u>Proportion of Sectoral Energy Demand</u>	<u>Major End Uses</u>
Residential	25%	Space and water heating, appliances
Commercial	17%	Heating and cooling
Industrial	27%	Electricity specific applications (primarily ore processing and handling)

Electricity is available in Yukon on the interconnected Whitehorse-Aishihik-Faro (A/W/F) and Mayo systems and at off-grid locations. Power for the A/W/F and Mayo systems is produced by the Northern Canada Power Commission, primarily from hydro-electric sources. Diesel generating units are used on these systems when required. Power at off-grid locations is produced by the Yukon Electric Company from diesel generating units.

(1) R.A. Hodge, op. cit.

(b) Potential Sources and Uses

In addition to well established current uses, electricity in Yukon could have such future applications as the powering of compressor stations along major oil and gas pipelines which may be built through Yukon, or as an input to the production of hydrogen. It has been estimated, for example, that if compressor stations along the proposed Alaska gas pipeline were to be fuelled by electricity, approximately 150 MW of electrical power would be required.⁽¹⁾ Potential use for the production of hydrogen is discussed in section 2.11 below.

In addition to the two existing sources of electricity in Yukon - diesel thermal and hydroelectric power - electricity could be supplied by a variety of means, including non-diesel fired thermal sources (e.g. coal, wood, geothermal, gas) and solar and wind. Inter-connection with Alaska, B.C. or Alberta could also be considered. As to the availability of electricity to users in Yukon, this could be extended by expansions of existing grids or alternatively, by introduction or expansion of off-grid facilities.

(1) Northwestern Associates Ltd., Foothills Natural Gas Transport System and Its Potential Impact on Electric Power Supply and Uses in the Yukon, November 1977.

(c) Cost Analysis

Existing Source:- NCPC estimates that the current wholesale cost of hydroelectric power at Whitehorse is 5¢/kWh or approximately \$14/GJ. The current wholesale cost of diesel-generated electricity at Whitehorse is estimated at 16¢/kWh or approximately \$44/GJ.⁽¹⁾

Electricity costs facing users include distribution as well as the wholesale cost of power. Based on NCPC and YEC rate schedules (see Table II.7) and on average annual load and load factor characteristics, the current average delivered cost of electricity in the Whitehorse area is estimated at \$.063/kWh or \$17.50/GJ.⁽²⁾

Costs at other locations in Yukon are considerably higher because of the reliance on diesel, additional fuel transportation costs and smaller market size. Rates at Dawson City, for example, are estimated at \$50/GJ to \$67/GJ depending on the customer category. At Johnson's Crossing, domestic charges are estimated at about \$97/GJ.⁽³⁾

(1) NCPC, "Proposed Rate Adjustments Effective April 1983". This is lower than the estimated cost from new diesel facilities (Table II.6) in part because of the difference in capital cost, and in part because of rising diesel costs.

(2) Ibid.

(3) Ibid. It should be noted that these rates do not fully reflect electricity costs at these locations.

TABLE II.7
Electricity Rates in Whitehorse Area

	<u>NCPC</u> ^a	<u>YEC</u>
Residential	- \$63.60/yr. service charge - 11.26¢/kWh energy charge for all consumption	- \$36/yr. customer charge - 5.37¢-6.22¢/kWh energy charge depending on level of consumption^b
Commercial/Industrial	- service charge of \$254.40/yr. or \$4.24/kW whichever is greater - 11.48¢/kWh for all consumption	- \$1.00/kW demand charge - 5.37¢-7.46¢/kWh energy charge depending on consumption^b

Source: Current NCPC, YEC Service Rate Schedules effective April, 1983 and June, 1981, respectively.

- (a) Applies to all residential and commercial customers on Whitehorse to Faro 138 kV transmission line other than to Northwest Telecommunications and Braeburn Lodge.
- (b) Includes 0.8¢/kWh fuel and purchase power cost adjustment for Whitehorse.

Potential Sources:- Future electricity costs in Yukon will depend on how much is required and how it is produced. The economic, technical and environmental review of hydro-electric alternatives are discussed in this section. The assessment of non-hydro generation sources are discussed in the sections concerning the primary fuel source.

As discussed in the inventory chapter there are many potential hydro-electric sites in Yukon. The sites selected for analysis here are those for which relatively up-to-date feasibility studies have indicated good promise for development. Table II.8 shows the cost of electricity delivered to Whitehorse or the main interconnected grid from a number of selected hydro sites. It should be noted that more detailed feasibility work could significantly change the costs and relative attractiveness of the sites we have selected.

Energy output in this Table represents firm energy at the load centre. Firm energy represents the generation potential of the plant when operated at a constant rate during the year, utilizing the dependable regulated water flow based on the critical water period. The capital costs include site construction plus transmission line costs. The facilities are assumed to have a 60 year economic life.

As shown in Table 8, energy costs from all of the hydro sites are considerably lower than diesel-fired costs. The lowest costs are shown for the mid-Yukon site, which is a very large site for Yukon. Of the small hydro sites, McIntyre Creek exhibits the lowest energy costs at \$13.65/GJ.

In all cases the capacity costs (capital costs per MW) are very high, ranging from \$2500 per kW to over \$7000 per kW. This is much higher than potential diesel sources. Optimum development of the electric systems, therefore, will depend on the nature of the requirement (capacity vs energy) as much as the average energy cost.

It is interesting to note that all hydro sites shown exhibit significantly higher energy costs than existing hydro facilities. Thus, unless new hydro is able to displace diesel, electricity costs to users will rise in real terms in the future, depending on how fast high cost new facilities are added to the system and on how much diesel is displaced. Offsetting this in the rates will be the cost-reducing impact of the depreciation of existing facilities, but this will not diminish the rising marginal costs of meeting new additional supply.

TABLE 11.8

Average Levelized Energy Costs
and Average Capacity Costs
for Selected Hydro Sites in
Yukon

	<u>McIntyre Creek</u>	<u>Squanga Creek</u>	<u>Liard River</u>	<u>Ross Canyon</u>	<u>Hootle Canyon</u>	<u>False Canyon</u>	<u>Mid Yukon</u>
Capacity (MW)	.75	1.75	3.8	30.0	40.0	58.0	240.0
Energy Capability (GJ)	20,734	24,833	29,518	567,600	756,800	1,097,365	4,540,820
Capital Costs ('000\$)							
On Site	3,500	10,350	12,080	206,910	164,560	287,738	601,920
Transmission	-	650	1,443	13,200	18,000	72,000	7,000
Total	3,500	11,000	13,523	220,110	182,560	359,738	608,920
Operating Cost ('000\$)	50	110	122	2,201	1,826	3,597	6,089
Average Levelized Cost Per GJ (\$)	13.65	33.92	34.63	29.69	18.47	25.10	10.27
Capacity Cost/Kw(\$)	4,666	6,286	3,559	7,337	4,564	6,202	2,537

Source: YEC for McIntyre Creek; NCPG and Monenco for all other sites.

- Notes: (1) Assumes economic life of 60 years; costs up-dated where necessary on basis of 10% annual cost factor.
- (2) Transmission costs to grid or nearest load centre estimated on basis of average cost per km of transmission requirement.
- (3) Operating costs for most sites estimated at roughly 1% of on-site capital cost.
- (4) Liard R. site 16 km SE of Watson Lake. While the costs of this project are attractive, larger scale development of the Liard is considered by Monenco to be a more efficient utilization of hydro potential on this system.
- (5) Mid-Yukon estimates are for stages 1 and 2 of the development. A third stage would add an additional 240 MW of capacity at an estimated cost of about \$1,400/kW.

(d) Other Assessment Factors

Technical and Long Term Resource Constraints:- The use and reliability of larger scale hydro-electric facilities distributing power over long distances to load centres by means of high voltage transmission lines has been well established in Canada, since the early part of the century.

The ability of a hydro plant to produce firm energy depends on upstream storage capacity. Therefore, hydro systems are generally termed "energy critical" - that is, the most important planning problem is to provide sufficient storage to generate power when water flows are low.

As indicated in the Yukon Energy Inventory Chapter, the hydro-electric potential of Yukon is also very large. The main impediment to the development of larger scale hydro facilities in Yukon is the very small size of the interconnected load and the current depressed state of the economy, particularly in the mining sector. Without a substantial increase in economic activity, utilization of a large new hydro facility would be very low. Given the relatively high capital costs of such facilities the per unit costs of hydro-electricity would be very high.

The attractiveness of a particular site as a source of hydro power depends on a number of hydrological, topographical and geological factors totally independent from the location of load centres. Thus, another disadvantage of hydro is that transmission lines to load centres or the interconnected grid may be required resulting in higher costs and line losses. The significance of transmission costs can be seen in Table 8.

Small hydro plants (e.g. less than 5 MW capacity) are more suited to smaller loads, particularly in off grid communities. Small hydro facilities supplying power to local communities were quite common at the turn of the century, and there were as many as 20 manufacturers of small turbines in Canada. The development of electric power transmission removed the limitation on the size of a hydro development. Economies of scale of larger generation units and, at the time, low cost diesel fuel contributed to the demise of small scale hydro.⁽¹⁾ Rising oil prices and costs of increasingly inaccessible large scale hydro sites has forced a reappraisal of small hydro.

From a technical perspective, the main problem with small hydro facilities relates to construction problems inherent in a remote location. Also small hydro plants are limited in capacity relative to

(1) See Canmer Consultants, Considerations for Small Hydro Developments in Off-Grid Locations, Mar., 1982.

large scale facilities since they tend to be run of stream plants with less storage.

An inventory of small hydro sites is currently being undertaken for Yukon Electric, but information is not yet available. The major constraint from a resource availability perspective is that small scale facilities do not warrant the construction of long transmission lines and therefore must either be close to load centres or the interconnected grid. These sites must also be screened for environmental and engineering acceptability. The high fixed costs of pre-investment work which must be incurred before the proponent has any assurance of financial feasibility is in itself a constraint to the development of smaller hydro.

A major advantage of both large and small scale hydro is that such plants have a very long life - a common assumption for feasibility assessment purposes is 60 years - and that operating costs are almost negligible. Therefore, while capital costs for such facilities are high, energy costs are relatively immune to inflation.

Environmental and Economic Impacts:- The environmental impacts of hydro development pertain largely to the impact related to reservoir flooding and to changes in downstream water flows. Resources and activities such as forestry, agriculture, wilderness recreation, hunting and fishing can be affected by hydro developments.

The construction of a hydro facility will provide a considerable amount of economic activity within the region. This is due to the fact that on site construction activity accounts for a large proportion of total capital costs. For example, of the total direct capital costs of approximately \$609 million (1983 \$) for the Mid Yukon project, about 60 percent is accounted for by such components as dams, diversion, spillway canals etc. These are items which must be constructed on site, as opposed to generators which are purchased outside the Territory. On-going employment with hydro power, however, is very small.

2.3 Propane

(a) Existing Sources and Uses

Propane is used primarily for heating and cooking purposes. It is currently transported to Yukon by barge from Vancouver and by truck over the Alaska Highway from Taylor, B. C. and from Alberta sources.

(b) Potential Sources and Uses

In addition to current uses, the other most important potential use for propane would be as a transportation fuel. Potential sources of propane include recovery as a processing by-product of Yukon natural gas production. The natural gas field which holds the most promise in this regard is the Eagle Plains field. The Kotaneelee field in the southeast corner produces a dry sour gas, according to discussions with a gas plant operator in the area.

Another source would be the further processing of gas from the Alaska Gas Pipeline when and if such a line is built. However, it would be extremely expensive to build a straddle plant on the Alaska pipeline at Whitehorse to recover the small fraction of propane that remains after initial processing in the field. The costs would be prohibitive. Only if a petrochemical complex could be developed at Whitehorse might it be economical to build a straddle plant to recover ethane and other gas liquids such as propane. This development is also unlikely in the foreseeable future.

(c) Cost Analysis

Fuel Cost:- The current retail price of propane ranges from \$15.50/GJ in Whitehorse to about \$25.25/GJ in Faro.⁽¹⁾ Net of territorial excise taxes, the retail cost of propane is slightly lower at \$15.40/GJ in Whitehorse and \$25.15/GJ in Faro.⁽²⁾

Future propane prices will depend on the source. Propane from existing refinery and gas plant sources is likely to escalate at a real rate similar to refined petroleum products generally (.5% per year is assumed for purposes of this study).

In the case of propane produced from processing of Yukon gas reserves the incremental cost would be the opportunity cost of reduced natural gas energy content, the capital and operating costs of extraction facilities and transportation costs to Whitehorse and other communities. Cost estimates for these various components are not available at this time. In any case, such a development is contingent upon the economics of gas production in the area. Even if a gas market were to develop in the Yukon, it is doubtful this gas would be economic in the foreseeable future (See Section 2.9).

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1. Yukon Department of Economic Development and Intergovernmental Relations, Fuel Price Survey, April 15, 1983. Figures assume an average energy content of .0248 GJ/litre.
 2. A heating fuel tax of 2¢/l. is included in the current retail price of propane.

A recent study by Stone & Webster investigated the costs of providing propane within Yukon in a gaseous state by a distribution pipeline system, rather than by truck. Propane would be delivered by truck to Yukon and then gasified for distribution. In Table II.9, the estimated capital and operating costs of a propane vapour plant and distribution system are shown. With estimated sales reaching over 1.4 million GJ per year, the average levelized cost of the system (over an assumed 25 year life) would be slightly over \$7.00 per GJ. This, of course, would be in addition to the cost of propane itself.

Utilization Cost:- In Table II.10, the average levelized cost of using propane for residential space heating are shown.

For conventionally-supplied units, an efficiency factor comparable to oil (65%) and equipment costs of \$1,500 are assumed.⁽¹⁾ For a vapour system, an efficiency factor comparable to natural gas (90%) and furnace costs of \$4,000 are assumed.

The table indicates that the costs for a conventional system are somewhat less at \$25.40 per output GJ. The vapour system has lower output energy costs in later years but not enough to offset the higher costs in the earlier years.⁽²⁾ Relative to other sources, including heating oil, in both cases propane exhibits high costs.

(1) Stone & Webster, op.cit.

(2) In the early years, the higher capital costs of the vapour system give rise to its higher energy cost. In later years, as energy prices rise, the fuel component of the cost is of greater significance and the higher efficiency of the vapour more than offsets its higher initial cost.

TABLE II.9

Propane Vapour Plant
and Distribution System
Costs

<u>Year</u>	<u>Production Plant Cost</u> ('000\$)	<u>Distribution Plant Cost</u> ('000\$)	<u>Production O & M</u> ('000\$)	<u>Distribution O & M</u> ('000\$)	<u>Sales</u> ('000\$)
1988	4540				
89	10798	1392			
1990		1730	1671	156	367.10
91		2839	4461	614	973.98
92		2340	6294	986	1354.36
93		602	6708	1102	1408.72
94			7032	1110	1447.08
95			7113	1105	1453.97
96			7270	1105	1467.29
97			7270	1105	1467.29
98			7270	1105	1467.29
99			7270	1105	1467.29
2000			7270	1105	1467.29

Average Levelized Cost - \$7.06/GJ

Notes:

- (1) The full distribution system is assumed to be in place by 1996 and O & M and sales are assumed to remain constant thereafter.
- (2) In calculating average levelized cost an operating life of 25 years is assumed.

Source: Stone & Webster, op.cit.

TABLE II.10
Average Levelized Cost of Propane
in Heating Applications

	<u>Conventional Propane Heat</u>	<u>Propane Vapour Heat</u>
1983 Fuel Cost (\$/input GJ)	15.40	22.45
Escalation Rate (%/Yr.)	.5	.5
Efficiency Factor	.65	.90
Furnace Costs (\$)	1,500	4,000
Furnace Life (Yrs.)	15	15
Average Annual Energy Output (GJ/household)	150	150
Average Levelized Cost per Output GJ	25.41	27.40

Note:

- (1) Fuel cost based on Whitehorse propane prices and estimated vapour system cost as shown in Table II.9
- (2) Escalation in propane vapour heat applies only to fuel component of cost (i.e. not the plant and distribution costs).

(d) Other Assessment Factors

Technical and Resource Availability Constraints:- The utilization of propane as a heating fuel is well established and reliable. Utilization as a transportation fuel is gaining wider acceptance in other parts of Canada, particularly for commercial fleets, although its applicability in northern conditions remains to be tested.

Probably the most important constraint to propane useage as a transportation fuel is that its distribution system is not as extensive as for RPP's. A major advantage claimed for propane is that it burns very cleanly, thus reducing engine maintenance costs and prolonging engine life.

A disadvantage of propane is that its market price tends to track oil prices and thus variations in oil prices will affect the price and competitiveness of propane.

Environmental and Economic Impact:- The environmental impacts of local propane processing (i.e. a straddle plant on the Alaska Gas Pipeline or an extraction plant at Eagle Plains) are unknown. The piping of vaporized propane would result only in relatively minor, short term environmental dislocation. At the utilization end propane is a very clean burning fuel and would substantially reduce auto air pollution if adopted widely as a transportation fuel.

The economic impacts in Yukon generated by the construction of local extraction plants or pipelines would be significant but such facilities are very capital intensive in nature and long term operational impacts would be minor.

2.4 Wood and Wood Waste

(a) Existing Uses and Sources

There is widespread use of wood heaters for space heating of private residences in Yukon. Hodge⁽¹⁾ estimates that almost one-fifth of residential space heating energy requirements are currently provided by wood and that this proportion will grow over time.

Chip-fired space and water-heating Vyncke boilers have recently been installed at the school and at Selkirk band-owned buildings in Pelly Crossing as demonstration projects under the Yukon-Canada Conservation and Renewable Energy Demonstration Program (CREDA). The Cattermole Timber sawmill at Watson Lake includes a chip-fired steam plant to supply its power and heating requirements. The possibility of supplying the nearby community with power and heat is being considered.

The wood supply for domestic heaters in Yukon is based primarily on firekill timber areas near communities. The source of supply for the chip-fired boilers at Pelly Crossing is a very large firekill area near the community.

(1) T. Hodge, op.cit.

(b) Other Potential Sources and Uses

Other major potential uses of wood as an energy source in addition to those already existing in Yukon include the production of power and heat from wood gasifiers, steam plants or burners of various types.

(c) Cost Analysis

Fuel Cost:- The fuel cost of wood on an input GJ basis depends on the delivered cost of the wood and its energy content.

Estimates of delivered cordwood costs in the Whitehorse area range from \$50-\$85/cord or \$22-\$38/m³(1) in the Whitehorse area, with the higher end of the range more reflective of the price required to cover all wood harvesting and delivery costs (including equipment replacement) in a commercial enterprise.(2) It is the high end of the price range which can be taken as a proper economic measure of wood cost.

(1) Based on 2.26 m³ of solid wood in a cord.

(2) Sources: Department of Tourism and Economic Development, Fuel Price Survey, April 15, 1983; T. Hodge, op. cit.; D. Harder, sawmill operator.

In different communities wood costs will vary depending on distances from the wood source. Over time, hauling distances will affect wood costs for all communities. One can expect some real increase in wood costs as more accessible stands are exploited. Also, rising labour costs contribute to higher harvesting and delivery costs. For purposes of this study, wood costs are assumed to escalate at the same rate as oil prices, that is, 0.5% per year. A higher rate of increase is, however, quite possible.

With respect to wood chips, delivered costs will depend on their source. Wood chips derived from cordwood would be expensive, since it would require a chipper in addition to the purchase of the wood. Wood chips available from sawmill or from a dedicated chipping operation as at the Pelly Crossing Boiler system would cost less. Wood chip costs for Pelly Crossing are estimated at \$8.50/m³(1)

Wood available for energy purposes in Yukon is mostly soft-wood species such as pine and spruce. The energy content of cordwood and chips is estimated at about 7.1 GJ/m³ of solid wood.(2) Thus, the current fuel cost of cordwood is about \$5.30 per input GJ. The current fuel cost of low cost (dedicated) chips is about \$2.50 per input GJ.

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- (1) Energy, Mines & Resources, Project Summary: Pelly School Wood Chip Boiler System, July, 1982.
 - (2) Reid, Collins Alaska Inc., Use of Wood Energy in Remote Interior Alaskan Communities, September, 1981. Based on assumption that a given volume of wood chips is equivalent to the same volume of solid wood.

Utilization Costs - Heating Applications:- With respect to direct use of wood for heating purposes, two examples are assessed - that of a domestic airtight heater and that of a chip-fired boiler for larger commercial/institutional buildings. Domestic air-tight costs are based on data for wood heat installations under the Canada Oil Substitution Program in Yukon. The chip-fired boiler costs are based on a Vyncke boiler system, one of many types which could have been selected for illustrative purposes.

The combustion efficiencies are estimated at .55 for a wood stove and .60 for a wood-fired boiler.⁽¹⁾ These estimates reflect more efficient combustion for chips because of greater surface burning area. Based on the costs, energy output and economic life as shown in Table II.11, the unit levelized costs of space heating with wood are estimated at \$11.21 per output GJ for an airtight and \$6.56 per output GJ for a wood-fired boiler.

(1) Sources: EMR Project Summary: Pelly School Wood Chip Boiler System, July, 1982; R.A. Hodge; op.cit.

These costs compare very favourably to heating with other existing sources and explain why wood is increasingly popular in the region.

TABLE II.11
Average Levelized Cost
for Selected Wood
Space Heating Technologies

	<u>Air Tight</u> ⁽¹⁾	<u>Wood-Chip Fired</u> ⁽²⁾ <u>Boiler</u>
1983 Fuel Cost (\$/input GJ)	5.30	2.50
Escalation Rate (%/Yr.)	.5	.5
Efficiency Factor	.55	.60
Equipment Capital Cost (\$)	1,400	125,400
Equipment O & M Cost (\$/Yr.)	50	980
Equipment Life (Yrs.)	15	15
Average Annual Energy Output (GJ/household or institution)	150	960
Average Levelized Cost per output GJ	\$11.21	\$6.56

Notes:

- (1) Average cost of residential wood heat installations assumes professional installation and includes all accessories such as stove pipe, roof flashing, fire proof insulation, etc. Maintenance cost represents bi-annual chimney cleaning. Wood requirements and energy output based on average annual heating requirements for existing housing in Whitehorse as estimated by Hildebrandt-Young, op. cit.
- (2) EMR, Project Summary: Pelly School Wood Chip Boiler System, op. cit. Costs and specifications for a Vyncke boiler with automatic feed plus ancillary equipment.

Utilization Cost - Wood Generated Electricity:- Wood can directly be used to produce electricity in a steam plant or can be gasified for electric power generation purposes. In Table II.12, electricity costs for the latter are shown, based on the Fort Providence, N.W.T. gasification demonstration project.

As shown in the table, electricity costs are quite high, much higher than diesel, for example. If operated at a load factor comparable to that assumed for diesel, the average levelized cost would be about \$96/GJ of electricity produced. As a base load facility, operating at a maximum capacity factor of .80, the average levelized cost would be about \$54/GJ.

It is possible that direct combustion of wood in a steam plant would produce lower costs, but data on such facilities (like the small plant of Cattermole Timber's sawmill in Watson Lake) are not available at this time.

It is also possible, indeed very likely, that lower costs would result in the combined production of power and heat. Data on this, too, however are not available.

TABLE II.12
Average Levelized Cost
of Wood Gasifier Electric
Power Generation

	<u>Base Load</u>	<u>Low Load Factor</u>
1983 Wood Cost (\$/input GJ)	2.50	2.50
Escalation Rate (%/Yr.)	.5	.5
Efficiency Factor (input wood/ output electricity)	.17	.17
Capital Cost ('000\$)	500.00	500.00
O & M Cost ('000/Yr.)	65.00	65.00
Average Load Factor	.80	.38
Plant Life	30	30
Average Levelized Cost per electricity output in GJ	\$53.56	\$96.02

Notes:

(1) Based on 120 kW facility.

Sources: Reid Collins, op.cit.; S.O. Phillips, Wood Gasification for Power Generation and District Heating, Fort Providence, N.W.T.; Crippen Consultants, Feasibility Study for Wood Gasification and Small Scale Hydro Power Generation for Indian Reserves, March 1982.

(d) Other Assessment Factors

Technical and Long Term Resource Constraints:- The use and reliability of domestic wood heaters in Yukon is well established. Chip-fired, space heating boilers are also established in other jurisdictions although technical feasibility and reliability in Yukon conditions require further demonstration. Wood-fired steam plants generating power and heat are quite common in the forestry industry in North America.⁽¹⁾ Wood gasifiers are being tested on a demonstration basis in the Northwest Territories and Saskatchewan.⁽²⁾ All of these technologies have the advantage of being somewhat fuel flexible. The necessity of having trained personnel operating such gasifiers and steam plants 24 hours a day is a constraint in remote locations. Generally their operation and maintenance is more complicated than conventional technologies.

(1) For example, of approximately 130 pulp mills in Canada, about 60 already have hog fuel boilers for cogeneration purposes. See Energy, Mines and Resources, Opportunities for the Use of Biomass Energy in the Industrial, Commercial and Institutional Sectors, Report ER 181-4E, March 1981.

(2) For example, an automated wood gasification plant has been established under the Canada/NWT CREDA to provide power and heat for a 3700 ft.² commercial complex in Fort Providence.

One disadvantage of wood as a fuel, which makes its collection, transport and handling relatively expensive is its bulk and weight in relation to its energy value. Green standing timber also has a high moisture content at the time it is harvested which reduces its value. Drying the wood increases its heat value per unit volume, but air-drying takes a long time and large quantities of wood have to be stored if a constant supply is to be maintained. Quicker drying in heated kilns requires additional energy. This problem is not as important in Yukon where firekill timber is the main source of firewood.

Wood is a variable material and in crude form does not burn evenly because of varying piece size, moisture content and species. This can be improved by changing wood from log form into chip form. Chips can be handled more conveniently by conveyor and hopper systems, can be dried more quickly and evenly and they present a greater surface areas for more efficient combustion.

Extracting selected gases, liquids and solids from wood by fermentation, pyrolysis, chemical reduction or enzymatic reduction yields fuels with greatly increased heat value per unit weight. However, most of the extractive procedures are sophisticated and relatively expensive.⁽¹⁾

(1) For a discussion of the characteristics of wood as a fuel, see Reid, Collins, op. cit.

Estimates of the Annual Allowable Cut of standing timber for energy purposes for the major population corridor along the Yukon River, (including Whitehorse) indicate no long term sustainable supply constraint, in aggregate at least. Current firewood harvests represent only a very small fraction of the estimated AAC for these regions, which do not include firekill timber volumes. However, the inventory information readily available at present is not sufficiently detailed to identify firewood supply constraints for individual communities. Accessibility of firewood, especially around Whitehorse, will become more and more difficult over time and delivered costs will likely rise in real terms, particularly if larger scale wood-fired technologies come onstream.

Environmental and Economic Impacts:- The environmental impacts of wood harvesting, including loss of wildlife habitat, soil erosion and degradation of fish streams, can be largely mitigated by appropriate management and operating practices. Cutting of deciduous species and thinning can enhance saw timber values. Because northern forests tend to be understocked, intensive management could increase forest productivity in the future.

As a fuel, wood is virtually sulphur-free compared to oil and coal so it does not aggravate sulphur-dioxide air pollution. It does, however, emit more particulates and carbon monoxide than oil or gas because of incompletely burned carbon and oxygen.⁽¹⁾ There are already concerns in the Whitehorse areas about air pollution from wood heating. Widespread adoption of wood burning heaters could aggravate the problem. Wood gasifiers can produce toxic organic compounds and tars for which treatment or disposal is difficult.

In terms of economic impacts, wood harvesting is relatively labour-intensive and provides long-term employment. Local production of domestic heaters could likely be expanded. With respect to chip utilization, the boilers would be largely imported but new markets for chips could help stabilize local mills. Forest management activities (eg. planting and thinning) are also relatively labour intensive.

(1) M. Mohr, The Cloud Over Wood, Harrowsmith, pp. 78-82. Also S. Bayne, et. al., A Literature Review of the Possible Adverse Effects of the More General Use of Wood Stoves for Domestic Heating, 1981.

2.5 Coal

(a) Existing Sources & Uses

Historically, coal has only been mined in the Carmacks area where the coal was used thermally for plant heating and drying ore concentrate at Cyprus Anvil's lead-zinc mine at Faro.

(b) Potential Sources & Uses

As indicated in the resource inventory, there are a significant number of areas with coal development potential in Yukon including small scale localized deposits in the Tintina Trench and large scale deposits of thermal grade coal in the Bonnet Plume basin area.

Potential coal uses cover a wide range of applications. The most significant potential for Yukon is its use as feedstock for thermal-electric generation or for firing industrial boilers for process heat or process steam. Because of its bulkiness, coal utilization is most attractive at or near the mine site. For this reason, use of coal from the isolated areas --- such as Bonnett Plume --- appears to be limited to electrical generation. Coal from the Carmacks area, however, may be appropriate for direct industrial use or even in residential heating applications in briquetted form.

In addition to its conventional thermal uses, a number of non-conventional energy applications for coal exist. Coal can be liquified through pyrolysis to generate a slate of oil products with high diesel fuel yields. Coal can be gasified, yielding high quality methane gas suitable for the same energy uses as natural gas. Finally, coal can be used in units which currently use fluid (such as diesel fuel) combustion through mixing coal and oil in a slurry mixture for burning. Because of current uncertainties about technical and economic feasibility, however, evaluation of these applications has not been undertaken.

(c) Cost Analysis

Fuel Cost:- The cost of coal on an input GJ basis depends on mining and transportation costs and on its energy content. These factors and the resulting fuel cost will vary from deposit to deposit for a variety of reasons.

First, mining costs are closely linked to such factors as seam thickness, areal extent, depth of overburden, and the degree of isolation from existing infrastructure. All of these factors will affect mining costs, whether by underground or surface technique.

Second, the dollar cost per energy unit will depend on coal quality and energy content, which is subject to large variation.

Thus coal costs in Yukon will very much be site specific. At this time only limited or preliminary site specific information is available, so only very rough estimates can be made.

Mine-month coal costs for the Bonnet Plume area have been estimated by Monenco at about \$75/tonne in 1981.⁽¹⁾ No cost breakdowns of this estimate are available. Allowing for inflation results in a 1983 mine-mouth price of about \$85/tonne.

Because of the inaccessibility of the Bonnet Place area, a location cost factor of approximately 30% is used in relation to the Whitehorse area. This suggests that similar activity in the Carmacks area would cost about \$60/tonne of coal. Cost per GJ based on estimated energy content for three of the major coal-bearing areas in Yukon are shown in Table II.13. Briquetted coal involves an estimated 25% premium in areas where markets (principally residential) are available. Transportation costs to markets for direct use have not yet been estimated.

(1) Monenco Consultants Ltd., Yukon Thermal Power Generating Study for Pan Ocean Oil Ltd., May, 1981.

TABLE II.13
Costs of Coal Production

Area	Heating Value ^a (GJ/t)	Mine-Mouth Cost (\$/t)	Cost (\$/GJ)	
			Crushed	Briquette
Carmacks, North	25-30	60	2.00-2.40	2.50-3.00.
Carmacks, South	15-25	60	2.40-4.00	3.00-5.00
Bonnet Plume	20-25	85	3.40-4.25	4.25-5.30

(a) Sources: Monenco Consultants Limited, op. cit; Rod Hill, Mineral Economist, DTED, 1983.

Utilization Cost - Heating Applications:- In Table II.14, the average levelized cost of using briquetted coal for space heating applications are shown. Based on an average fuel cost of \$4.00 per input GJ, furnace costs of \$2000, furnace life of 15 years and a combustion efficiency of 30%, the average levelized cost is estimated at \$14.70 per output GJ. Despite the low combustion efficiency, the costs appear quite favourable, particularly compared to existing oil sources.

It should be noted, however, that the coal costs are quite rough and variations in the fuel cost have a marked impact on the average levelized cost. With input fuel costs of \$2.50/GJ, the average levelized cost of coal heat is \$9.70 per output GJ; with input fuel

costs of \$5.40/GJ, the average levelized cost is approximately \$19.40/GJ. Given that transportation costs have not been considered in the estimates, coal costs toward the higher end of this range are quite likely.

While coal use in residential applications may be competitive depending on the delivered coal cost, use in industrial boilers is potentially of greater attraction. Costs will, of course, depend on industrial requirements and boiler specifications. Costs for such applications have not been estimated.

TABLE II.14

Average Levelized Cost
of Coal Space Heating

	<u>Low Coal Cost</u>	<u>Medium Coal Cost</u>	<u>High Coal Cost</u>
1983 Fuel Cost (\$/input GJ)	2.50	4.00	5.40
Escalation Rate (%/Yr.)	0	0	0
Efficiency Factor	.30	.30	.30
Furnace Cost (\$)	2000	2000	2000
Furnace Life (Yrs.)	15	15	15
Average Annual Energy Output (GJ/household)	150	150	150
Average Levelized Cost per output GJ	\$9.70	\$14.70	\$19.37

Notes: (1) Furnace cost and life based on typical multi-fuel heating furnaces.

Utilization Cost - Electric Power Generation:- In Table II.15, the average levelized cost of producing electricity in a conventional coal-fired thermal plant is shown. On the assumption that the plant would operate as a base load facility, operating at its maximum capacity factor of 80%, and other cost factors are as shown in the table, the average levelized costs are relatively low at just over \$25/GJ. This compares favourably with several hydro sites and is considerably less expensive than diesel.

However, as shown in the table, if operated with a 38% capacity factor as assumed in the diesel-fired case, the energy costs are much higher, at almost \$40/GJ. This is still less expensive than diesel but would not be comparable to the better hydro sites.

TABLE II.15
Average Levelized Cost
of Coal-Fired
Thermal Plant

	<u>Base Load</u>	<u>Low Load Factor</u>
1983 Coal Cost (\$/input GJ)	3.80	3.80
Escalation Rate (%/Yr.)	0	0
Efficiency Factor	.30	.30
Plant Capital Costs (\$/kW)	1,746	1,746
Transmission Capital Costs ('000\$)	98,892	98,892
Plant O & M Costs ('000\$/Yr.)	4,906	4,906
Average Load Factor	.80	.38
Plant Life (Yrs.)	30	30
Average Levelized Cost per Electricity Output in GJ	\$25.28	\$39.21

Notes:

- (1) Assumes Bonnet Plume coal and plant location.
- (2) Assumes 70 MW capacity.
- (3) Includes transmission costs to A/W/F grid.

Source: Monenco, op. cit.

(d) Other Assessment Factors

Technical & Resource Availability Constraints:- The utilization of coal in conventional direct uses or in thermal electric plants is well established. The technology is reliable and is advantageous in that the depletion effect which tends to drive up the costs of fluid hydrocarbons is not so pronounced in the case of coal.

A disadvantage of coal development in Yukon is that it is not a readily transportable fuel and the large reserves (such as those in Bonnet Plume) appear to be too isolated to penetrate export markets in the foreseeable future. By implication, therefore, development of Yukon coal deposits depends exclusively on local energy demand, which is generally too small to justify high access and development costs.

Environmental Economic Impacts:- Although most of the coal in Yukon is fairly low in ash and sulphur content, recent environmental concerns (focussing on acid rain) have attracted attention to the need for controls on sulphur dioxide emissions. Although the assimilative abilities of the Yukon environment are quite high because of limited industrial development, such emissions could present both real and perceived problems near inhabited areas.

The development of a coal mining operation in Yukon would generate substantial employment income in both the construction and operation phases. There are also a number of other economic impacts which may be viewed as beneficial from the viewpoint of Yukon.

First, through developing the coal industry, infrastructure and transportation access will be put into place in the less developed regions of Yukon. Such decentralization would particularly occur if the Bonnet Plume area was developed. This infrastructure could create incentives for further coal, oil and gas, and mineral exploration with their associated future impacts and benefits.

Second, coal development utilizes proven technology which is readily available and, indeed, currently in surplus in Yukon with the slow-down in the mining industry. Yukon currently has an underutilized stock of mining labour and capital which could be put to work at a relatively low opportunity cost. As such, coal development could yield significant employment and income impacts to inhabitants of the Yukon.

Third, further development of Yukon's coal resources involves the establishment of long-term extractive industry capable of generating substantial royalties to the Territorial Government and individual landowners. As such, it offers an opportunity for diversifying the revenue and taxation base of Yukon.

2.6 Wind

(a) Existing Uses and Sources

Existing utilization of wind energy for electric power in Yukon is limited to private uses and to demonstration installations under the Canada/Yukon Conservation and Renewable Energy Demonstration Program (CREDA), namely:

- (i) a 200 W Windcharger supplying power for a radio-telephone and lighting in a wilderness guiding operation at Haines Junction; and
- (ii) a 1000 W generator supplying power for a family of four at Whitehorse.

Detailed wind speed and frequency data are being collected at 2 demonstration sites at Destruction Bay and Old Crow. These sites were established under CREDA to determine the performance and feasibility of wind generators in Yukon. Based on Department of Environment data for the small number of anemometer sites in Yukon, the southwest area of the Territory (including Whitehorse) appears to offer the most potential for development of windpower.

(b) Other Potential Uses and Sources

Potential uses of wind generators other than for production of electricity include wind-electric production of hydrogen and direct agricultural applications such as pumping water for irrigation. These uses are not assessed here, the former, because of the combined high costs and technical problems with windpower and hydrogen production; the latter because of limited relevance to Yukon.

If warranted by the performance of demonstration sites and uses under CREDA, a more comprehensive monitoring program is required to determine other potentially viable windpower generation sites.

(c) Cost Analysis

The most relevant utilization of wind energy for Yukon is for the production of electricity. The cost of wind-generated electricity depends on three factors: the capital and operating costs of the wind generation facilities; the expected amount of energy it will produce; and the expected life of the facility. These cost factors will vary depending on the size of the facility and the wind conditions where it is located.

In Tables II.16 and II.17 cost factors and resulting energy costs for small and larger scale wind generating facilities are shown. Cost data are based on various sources in B.C. and Alberta.⁽¹⁾ Wind and energy output data are also based on these sources since Yukon-specific data are limited. An effort was made to choose examples which roughly correspond to Yukon conditions, and the results are considered to be representative of the costs of windpower in Yukon compared to other energy sources.

Costs for smaller scale wind generators are based on a stand alone situation where provision for day to day storage is required due to fluctuations in wind conditions. Costs for larger scale units apply to situations in which wind generators are connected to an existing grid which provides back-up power. These costs are more speculative in nature since experience with large scale windmills is restricted primarily to demonstration models.

(1) ESL Environmental Sciences Ltd. and The IBI Group, An Assessment of Wind Energy Exploitation in British Columbia, October, 1981; B.C. Hydro, Alternate Energy Sources for Electric Power Generation, February, 1982; E.J. Wiggins, Prospects for Solar and Wind Energy Utilization in Alberta, December, 1978.

TABLE II.16
Average Levelized Costs
of Stand Alone Wind
Generated Electricity

	<u>2 kW</u>	<u>5 kW</u>	<u>40 kW</u>
Capital Cost ('000\$)	13.38	22.75	180.00
Annual Operating Cost ('000\$/yr.)	.36	.67	9.00
Average Capacity Factor	.15	.15	.25
Economic Life	15	15	20
Average Levelized Cost per Electricity Output in GJ	\$183.19	\$127.04	\$78.91

Notes:

- (1) Excludes land costs, but includes allowance for temporary power storage.

Sources: B.C. MEMPR, op. cit.; Wiggins, op. cit.

As shown in Table II.16, the small scale wind generators are very expensive, with energy costs ranging from \$78 to \$183/GJ on an average levelized basis. These costs are not directly comparable to other electricity generation, since the wind power would be generated at point of use and might not require grid distribution costs. However, even taking this into account it is clearly a more expensive source of electricity than conventional sources.

The costs exhibited for the large scale wind generators, on the other hand, are much lower. As shown in Table II.17 they range from \$21.70 to \$27.55 per GJ. These costs appear attractive to other sources of electricity, but it must be emphasized that they are not comparable in their output characteristics. Without storage facilities they must be used in conjunction with other generation sources. In effect they simply provide energy which could be used to displace the marginal fuel costs of electrical energy from these other sources. In the case of hydro the marginal fuel cost could be zero. In the case of thermal sources, it would be the fuel, but not equipment costs.

TABLE II.17

Average Levelized Costs
for Large Scale Wind Power
Generation

	<u>.5 MW</u>	<u>100 MW</u>
Capital Cost ('000\$)	770	235,000
Operating Cost ('000\$/yr.)	17.6	5,300
Average Capacity Factor	.25	.30
Economic Life	20	20
Average Levelized Cost per Electricity Output in GJ	\$21.71	\$27.55

Notes:

- (1) Excludes land costs and storage costs.
- (2) The 100 MW example assumes windfarm of twenty-five 4MW units.

Sources: B.C. MEMPR, op. cit.; B.C. Hydro, op. cit.

A promising potential use of wind generators is to couple them with a diesel generator to provide both mechanical (i.e. turning the diesel engine crankshaft) or electrical load sharing. For example, preliminary results from a demonstration project at Sudbury, sponsored by the Ontario Ministry of Energy in 1982 indicate unit levelized costs at about \$27 per output GJ (as measured in terms of diesel fuel savings). This estimate does not account for incremental operating and maintenance costs.⁽¹⁾

(1) Personal Communication, B. Stewart, Ontario Ministry of Energy.

(d) Other Assessment Factors

Technical and Long Term Resource Constraints:- Wind as an energy source is similar to solar in that resource availability is not a constraint per se -- the amount of power potentially available is very large -- but its very low "density" makes for poor generator efficiencies. It is also inherently variable, even more than solar on a daily basis, although variations in wind are more synchronous with seasonal load variations. Therefore, wind generators are likely to be most attractive as "fuel savers" or supplements to firm power sources such as diesel and hydro. This means that wind generators must be integrated with the existing grid and energy sources to assure continuous power with acceptable voltage/current characteristics.⁽¹⁾ Because of the marked geographical variation in wind speed and frequency, there is somewhat less flexibility in the siting of generators, although it is still generally possible to locate them close to the point of use.

Wind power generation and storage technology is relatively well-established for small and medium scale units outside of Yukon. (e.g. less than 50kW). For example, over 30 wind turbines in the 1-10 kW range have been operated in the bush regions of Alaska over the past

(1) See E.J. Wiggins, and ESL/IBI, op. cit. Wind generators produce power with high harmonics, and inconsistent voltage and signal.

six years. Apparently the technical problems with these generators (including blade icing, lubrication freeze-ups and storm damage) have been largely overcome. However, longer term reliability has yet to be established.⁽¹⁾ Large units have not yet been successfully operated on an uninterrupted, long term basis as yet. Vertical axis turbines (VAWT), although less efficient than propeller-type windmills, have a number of technical advantages.⁽²⁾

Environmental and Economic Impacts:- The environmental impact of wind energy is very minor for smaller point of use installations. Larger scale power generation by means of "wind farms" would require large amounts of land. However, given the relatively small electrical loads in Yukon, land use impacts of windmills are not likely to be a significant problem.⁽³⁾

The economic impact of wind power generation would result primarily from labour involved in installation. The capital equipment and technology would be mainly imported into Yukon and operating expenditures and labour would be very minor.

(1) Alaska Department of Commerce and Economic Development, State of Alaska Long Term Energy Plan, 1982.

(2) For example, VAWT's are omni-directional, require a shorter supporting tower and are inherently more stable than horizontal axis machines. See E.J. Wiggins, op. cit.

(3) For example, the land area occupied by wind generators with rotor diameters of about 12 m, minimum spacing of 6 diameters and providing power capacity of 1,000 kW, or 1 MW would be about 54 ha². See E.J. Wiggins, op. cit.

2.7 Solar

(a) Existing Uses

Solar's current contribution to energy supply in Yukon is negligible. Current use is limited to small private installations or passive design features in the residential sector. Several small demonstration projects have also been recently funded through the CREDA, including:

- (i) photovoltaic cells to power VHF communications stations in remote Yukon locations;
- (ii) solar collector to provide domestic hot water for a family of four in Whitehorse;
- (iii) greenhouse to contribute to space heating of existing home in Whitehorse;
- (iv) collector to contribute to the heating of a public swimming pool in Mayo and thermal blanket to conserve heat.

(b) Other Potential Uses

Other potential solar applications include active collector-based systems as well as passive design features for residential/commercial space heating. Active systems for industrial process heat (eg. for remote mining operations) are also possibilities.

(c) Cost Analysis

Solar energy can be utilized in a number of ways for a variety of applications.

Heating Applications:- In Table II.18 and II.19, average levelized costs for various heating applications are shown. Table II.18 summarizes the cost and output characteristics of active solar space and water heating systems. The table indicates average levelized costs ranging from \$43 to \$98/GJ in the separate active space and water systems, but \$23/GJ for an active combined system. With respect to passive solar, Table II.19 indicates average levelized costs of \$30/GJ for water heating and over \$80/GJ for space.⁽¹⁾

Considerable caution should be exercised in interpreting these tables. Firstly the data are derived from different sources for different locations and differences across systems may reflect this. Secondly, all of the sources are for regions further south than Yukon, which may understate average levelized costs for applications in Yukon. Thirdly, in all cases the energy output is not sufficient to meet total requirements, and therefore the systems must be recognized as supplementary to other sources. Thus it is the marginal fuel cost of the other possible sources to which solar costs should be compared. In this light, all solar residential heating applications with the possible exception of combined space and water systems would appear uneconomic.

(1) In this study active solar refers to those systems which require supplementary energy sources in order to operate. Passive solar applications do not require such supplementary sources for the system to function.

TABLE II.18

Average Levelized Costs for Active
Solar Space and Water Heating

System Description	Space			Water		Space & Water
Collector Size (m ²)	55.0	46.5	6.0	8.0	1.3	20.0
Capital Cost ('000\$)	15.9	17.23	2.1	3.7	4.6	7.1
Operating Cost ('000\$ /Yr.)	.11	0.13	0.03	0.11	.05	.12
Average Energy Output (GJ/yr.)	36.0	21.2	2.5	10.8	12.0	36.5
Economic Life (Yrs.)	15	15	15	15	15	15
Location	Van.	Edm.	S53°	Van.	Edm.	Van.
Average Levelized Cost per output GJ	\$48.38	\$89.53	\$98.19	\$45.34	\$43.42	\$23.11

Notes:

- (1) Costs and specifications are for liquid systems but these generally apply to air-based systems as well.
- (2) Short term, but not seasonal storage assumed in all cases. Seasonal storage would roughly double capital costs.
- (3) Longer equipment lives are quoted in the sources, but 15 years is used to be comparable to other heating sources.

Sources: B.C. Hydro, op. cit., for Vancouver separate space and water estimates, Acres Consulting, Solar Energy Resource Assessment Study for British Columbia, May 1980 for space and water combined, E.J. Wiggins, op. cit., for Edmonton estimates and W.A. Ross, The Cost of Energy from Active Solar Systems for S53° space heating.

TABLE II.19

Average Levelized Costs
for Passive Solar Space and
Water Heating Applications

	<u>Water</u>	<u>Space</u>
Capital Cost ('000\$)	2.7	13.8
Operating Cost ('000\$/Yr.)	.05	.05
Average Energy output (GJ/Yr.)	10.8	10.8
Economic Life	15	15
Location	Vanc.	Vanc.
Average Levelized Cost per output GJ	\$30.28	\$81.45

Notes:

- (1) Water refers to convection collector system.
- (2) Space refers to insulation and glazing measures in initially well-insulated house.

Source: B.C. Hydro, op. cit.

Electric Power Generation:- In Table II.20, the average levelized costs of solar-generated electricity are shown. As shown in the table, the cost of electricity from these sources is very high, making them impractical at their present stage of development.⁽¹⁾ Even the power tower, the most attractive of the three technologies considered, has energy costs over three times that of diesel.

TABLE II.20
Average Levelized Costs
for Solar-Generated
Electricity

	10 MW Flat Plate Photovoltaic	10 MW Photovoltaic Solar Concentrator	10 MW Power Tower
Capital Cost ('000\$)	395,000	63,000	106,000
Operating Cost ('000\$/yr.)	15,000	2,400	3,900
Average Capacity Factor	.15	.10	.20
Economic Life	35	35	35
Average Levelized Cost per Electricity Output in GJ	\$920.88	\$220.55	\$183.35

Notes:

(1) Excludes land costs and cost of temporary storage.

Sources: B.C. Hydro, op. cit.; E.J. Wiggins, op. cit.

(d) Other Assessment Factors

Technical and Long Term Resource Constraints:- The amount of solar energy potentially available is very large. Economics constitutes a much more severe constraint on use than the availability of solar energy. Its very low "density" results in generally poor collection efficiencies. However, the geographical incidence of solar energy is fairly uniform which means that it can generally be produced at the point of use and distribution costs are negligible or zero.

Probably the single most important problem with respect to solar space heating in northern latitudes is that radiation levels are lowest when space heating loads are highest.⁽¹⁾ This necessitates the tilting of collectors at a higher angle, the provision of larger collection and storage capacity relative to heating loads or the use of solar energy in inherently variable applications. Solar energy for space and water heating purposes is generally considered most feasible when complemented by conventional fuels.

(1) Seasonal variation in water heating demand is much lower and therefore does not present as great a problem.

Environmental and Economic Impacts:- Solar energy utilization involves no significant environmental impacts. Installations of solar systems are relatively labour intensive. Because of their bulky nature, and the economies of large scale production, system components are primarily manufactured in large industrial centres in Canada and the U.S. and shipped to Yukon in assembled form. The potential for greater local manufacturing fabrication of such components is limited.

2.8 Geothermal

(a) Existing Uses and Sources

The municipalities of Mayo and Whitehorse use naturally heated groundwater to supplement water supplies during winter months to prevent freezing. The Takhini hot springs near Whitehorse have also been developed as a recreational facility.

(b) Other Potential Uses and Sources

As outlined in the energy inventory section, a number of shallow, moderate temperature geothermal resources have been identified near several communities in Yukon. The entire Whitehorse-Carcross area bordering the Yukon River is classified as having hydrothermal convection potential, that is, systems in which heated water rises to the surface as a result of temperature differences with surrounding water. The quality and costs of developing these resources can only be estimated more precisely with further site-specific exploration.

The proximity of geothermal sites to several existing communities in Yukon and the fact that these are primarily low temperature systems, which are less costly to develop, suggests that the most immediately feasible uses of geothermal in Yukon are likely to be for

direct water and space heating rather than power production. Possible applications include space heating for recreational facilities, commercial, institutional or apartment buildings, mine air heating, mineral concentrate drying and processing, feedwater for domestic water supplies, de-icing of structures and roadway or airstrip surfaces and aquaculture.

High-temperature geothermal water may be flashed to steam for electric power generation using steam turbines. The amount of saturated steam produced is dependent on the temperature of the resource. With currently available technology an adequate supply of thermal water at temperatures greater than 180°C is generally considered necessary to produce electricity economically. Current research is directed at developing binary fluid power generating systems (heat exchanged to secondary working fluid with a relatively low flash point (eg. freon, propane, isobutane) that operate in the moderate temperature range (120°-180°C).

(c) Cost Analysis

Cost data for geothermal sources already developed in Yukon are not available. However, it is known that the development costs of these systems were very small since they involved tapping into known hot springs. As to the cost of new systems, that will vary depending on the quality and magnitude of the geothermal source and distance from point of use.

Based on discussions with Nevin/Sadlier-Brown/Goodbrand, geothermal consultants, some very rough order of magnitude costs were developed for a shallow low temperature water well near Whitehorse. Such a well would be capable of providing the total space and water heating loads for a number of government, institutional or commercial buildings in Whitehorse. The approach taken was to generate a range of unit levelized costs per output GJ to the user based on fixed exploration and development costs and a range of possible energy outputs and delivery distances. These costs are summarized below in Table II.21.

It is assumed that direct heating within a geothermal source will involve water-based distribution and appropriate exchangers (e.g. water-to-water or water-to-air) at the point of use. Building conversion requirements and costs are derived from estimates by Atcor in their feasibility study of waste diesel energy utilization which also assumed water-based distribution and exchanger systems.

As shown in the table, the estimated average levelized costs of geothermal heating could be quite low. A "good" resource would yield costs of approximately \$7.30/GJ; the "poor" resource slightly over \$12/GJ.⁽¹⁾ It should be recognized that the estimates are not based on specific Yukon cost studies or experience and therefore must be treated as illustrative of a potential, subject to considerable uncertainty. It should also be noted that the average levelized costs

(1) A wide range of levelized costs would have resulted if the "poor" resource had been combined with longer distribution distances and vice versa.

are predicated on the assumption that all of the energy output from the resource can be utilized. Nonetheless the results do suggest that geothermal could be economically attractive as a direct heating source.

Because the nature of the resource is so uncertain, cost data for electric power generation are not shown. However, it should be noted that if good quality resources can be found and sufficient demand exists to utilize the output, geothermal electricity generation could be attractive relative to other sources in Yukon. Data on geothermal projects in other jurisdictions indicate levelized costs of less than \$10/GJ can be realized.⁽¹⁾

(1) See, eg. B.C. Hydro estimates for Meager Creek in B.C. Hydro, op. cit.

TABLE II.21

Average Levelized Cost
of Direct Geothermal Heating

	<u>Quality of Resource</u>		
	<u>Poor</u>	<u>Fair</u>	<u>Good</u>
Capital Costs ('000\$)			
- Exploration	100.00	100.00	100.00
- Development	75.00	75.00	75.00
- Distribution	115.00	575.00	1,150.00
- User Installation	47.7	177.3	476.7
Operating and Maintenance ('000/yr)			
- Well & Dist.	19.0	65.0	122.5
- User Maintenance	4.8	17.7	47.7
Average Energy Output (GJ/yr.)	4,425.0	16,425.0	44,025.0
Economic Life (Yrs.)	30.0	30.0	30.0
Average Levelized Cost per Output GJ	\$12.12	\$9.85	\$7.32

Notes:

- (1) Assumes 150 m. well depth, 8" hole and casing.
- (2) Assumes distance to point of use of 1 to 10 km. (higher for poorer quality resource).
- (3) Assumes user installation costs based on building conversion costs estimated by Atcor Engineering, Whitehorse Rapids, Waste Heat Recovery Feasibility Study, Phase I, Feb. 1983.
- (4) Assumes heat recovery of 75%.
- (5) Based on discussions with Nevin/Goodbrand/Sadlier-Brown.

(d) Other Assessment Factors

Technical and Long Term Resource Constraints:- The technology for heating and power generation applications is well established throughout the world. For example, as of June, 1982 worldwide geothermal electric capacity is estimated at 2260 MW, comprised of over 120 individual power units.⁽¹⁾ Resource availability in Yukon is really unknown at present but development of geothermal would likely be limited initially to those sites which are near existing communities or the interconnected grid.

One disadvantage of geothermal is that exploration, drilling and testing costs are totally at risk until a particular site is proven. This is similar to oil and gas exploration. However, once installed, geothermal-based energy systems have low operating costs and are relatively inflation-proof.

Environmental and Economic Impacts:- The environmental impact of geothermal development is likely to be minor. As with fossil fuels, the exploration and development of geothermal sources is very capital versus labour intensive. A high proportion of jobs in exploration, drilling, development and the laying of pipe require relatively high skill levels. Most of the equipment and materials will be imported into Yukon. Operating costs and employment will also be very minor. Thus, overall, the short and long term economic impact of geothermal development will be small per dollar of capital invested.

(1) R. Dipippo, Overview of Worldwide Geothermal Power Development, Geothermal Resources Council Bulletin, May, 1983.

2.9 Natural Gas

(a) Potential Sources and Uses

Natural gas is not currently available to meet Yukon energy requirements, but if made available could be used for heating, power generation and transportation purposes.

The most likely potential sources of natural gas to the Yukon are:

- (i) natural gas from the Alaska Highway Pipeline, if and when that line is built or alternatively, natural gas from the Dempster Lateral which would connect Mackenzie Valley resources to the Alaska line near Whitehorse;
- (ii) development of natural gas resources within Yukon, the two prime areas being the Eagle Plains field in northern Yukon and the Kotaneelee field in the southeast corner of Yukon;
- (iii) natural gas from Dome's proposed LNG plant at Grassy Point in B.C.

Potential uses for natural gas include conventional space, water and process heating applications; in compressed form, transportation fuel; and finally, a fuel source for electricity generation.

(b) Cost Analysis

Fuel Cost:- Natural gas costs in Yukon will depend on the source and field price of the gas and on the transmission and distribution requirements and costs.

In a natural gas feasibility study recently undertaken by Stone & Webster, a variety of natural gas sources and transportation modes were examined. In Table II.22, the average cost-of-service of each of these sources, as estimated by Stone & Webster, are shown.

The table clearly illustrates that the Alaska Highway alternative is far more attractive than any of the others. The transmission and liquifaction or other facilities required in the other alternatives make them expensive sources of supply.

TABLE II.23
Average Levelized Cost of
Natural Gas from the Alaska Gas Pipeline at Whitehorse
(1983 \$)

<u>Year</u>	<u>Distribution Capital Costs (\$000)</u>	<u>Distribution O-M Costs (\$000)</u>	<u>Gas Costs (\$000)</u>	<u>Whitehorse Gas Sales (000 GJ)</u>
1989	1191			
1990	1568	175	1129	386.95
91	3135	668	2921	995.01
92	3255	1186	4214	1428.47
93	1137	1390	4469	1507.78
94	250	1456	4643	1558.41
95	258	1505	4704	1590.91
96	269	1564	4790	1592.09

Average Levelized Cost: \$4.54/GJ

Notes:

- (1) Capital, O & M costs and sales from Stone & Webster.
- (2) Gas costs from Stone & Webster but adjusted to reflect .5%/yr. real increase from 1983 price of \$2.82/GJ (the Alberta border price). Stone & Webster had assumed \$3.11 in 1990 and zero increase thereafter.
- (3) Plant life of 35 years assumed.
- (4) Distribution O & M and sales assumed constant after 1996; gas costs escalate at .5%/yr.

Source: Stone & Webster, op. cit.

Utilization Cost - Space Heating Application:- If natural gas is made available in Whitehorse from the Alaska Highway pipeline it would be an important energy source for space heating purposes. In Table II.24, the average levelized cost of space heating with natural gas is shown. Based on a delivered gas cost of \$4.54/GJ, a furnace cost of \$4000, a furnace life of 15 years and a combustion efficiency of 90%, the average levelized cost is approximately \$7.80/GJ. It clearly would be an attractive source of supply. Indeed even a gas source that raised costs two and one-half times that amount would be attractive compared to oil heat.

Utilization Cost - Electric Power Generation:- In Table II.25, the average levelized cost of generating electricity with natural gas is shown. In a 3MW facility, comparable to a diesel-fired unit, the average levelized cost would be \$19.70/GJ. This is considerably less than diesel but it should be noted that this cost is for a gas-fired plant in Whitehorse. Gas-fired plants in other communities, requiring other transmission or liquifaction costs, would be much more expensive.

Utilization Cost - Transportation:- Like propane, natural gas, in compressed form, could be used for transportation purposes. In addition to a basic gas cost of approximately \$4.50/GJ, conversion costs of approximately \$2000 per vehicle would be incurred on the part of the user and distribution/compression costs would be incurred by the seller. While cost estimates for the latter are not available, it is possible that the resulting levelized cost would be lower than refined petroleum product sources.

TABLE II.24

Average Levelized Cost
of Space Heating with
Natural Gas

Average Levelized Fuel Cost (\$/input GJ)	4.54	
Efficiency Factor	.90	
Furnace Cost (\$)	4000	
Furnace Life (Yrs.)	15	
Average Annual Energy Output (GJ/household)	150	
Average Levelized Cost per output GJ		\$ 7.78

TABLE II.25

Average Levelized Cost of 3MW
Natural Gas-Fired Electric
Power Plant in Whitehorse

Average Levelized Fuel Cost (\$/input GJ)	4.54	
Efficiency Factor	.27	
Plant capital costs ('000\$)	900	
Plant O & M costs ('000\$/yr.)	17	
Average Load Factor	.38	
Plant Life (Yrs.)	15	
Average Levelized Cost per Electricity Output in GJ		\$19.67

Source: Medicine Hat Electricity Department, AERCB; Stone & Webster,
op. cit.

(d) Other Assessment Factors

Technical & Resource Availability Constraints:- Natural gas service from the Alaska line should prove to be a long run reliable service. There is however considerable uncertainty as to when or if the line will be built. The financing of the pipeline has not yet been determined, and in addition the market outlook in Canada and the United States raises questions about the economic viability of the line. Under these circumstances it is difficult for the Yukon to plan for natural gas service from the Alaska pipeline.

Natural gas generated electricity, has many of the same advantages as diesel with respect to flexibility of size, speed of installation, and simplicity of operation. Natural gas, however, is limited in location by the gas distribution system.

Environmental and Economic Impacts:- The environmental impacts of pipeline construction (in the case of an Alaska Gas or Kotaneelee pipeline) are generally short term and can be relatively minor, provided proper procedures are taken to protect the permafrost areas and the migratory patterns of the local wildlife. Shipment of LNG by tanker to Skagway and then by rail to Whitehorse would have

negligible environmental implications. At the user end, both natural gas and propane as direct energy sources or (in the case of gas) as a source of electricity generation are very clean burning fuels which generate much lower levels of air pollution than refined petroleum products.

The economic impacts generated by development and delivery of natural gas and propane to Yukon will largely derive from natural gas pipeline construction which would generate substantial employment. Supplies and equipment for the pipeline would largely be imported. The delivery of LNG will generate only minor employment and income in Yukon. With respect to gas generated electricity, on-site construction would be minor and the majority of equipment would be purchased outside Yukon.

2.10 Peat

(a) Existing Uses and Sources

Peatlands in Yukon are widespread but currently the only uses for peat are horticultural in nature.

(b) Potential Uses and Sources

The potential sources of peat supply in Yukon were described in the inventory review. It should be noted that, in terms of accessing peatlands of potentially commercial size, the best prospects exist in the vicinity of Dawson. Peatlands further south in the Whitehorse area are quite sparse.

As an energy source peat is most suited to applications such as space peat heating or in firing boilers for process heat or process steam. Peat is particularly suited to such stationary applications because, in its most compact form, it consists of whole or crushed briquettes similar to low quality coal.

Normally, dried peat is burned in air to produce a flame. Research being undertaken by the Ontario Research Foundation,⁽¹⁾ however, indicates that wet peat can also be burned by wet oxidation when placed in an environment at high temperatures and pressures. Under wet oxidation, energy is released although no flame is produced. Also, wet peat may be used in a mixture with oil or methanol to be burned in conventional boilers.

(b) Cost Analysis

An accurate analysis of the costs of peat production for Yukon is not possible for a number of reasons. First, costs are site-dependent as they are very much a function of the location, accessibility, depth, areal extent, and quality of the peat bog. Second, there is no published experience anywhere in the world relating to development of peat bogs in northern climates with discontinuous or continuous permafrost.

The purpose of this section, therefore, is to indicate the types of production processes involved, and to present an example of what a typical development cost might be in southern climate using conventional technologies.

(1) Oilwells, June 20, 1983, p. 28.

The basic process involved in developing a peat bog commences with removing as much moisture from the peat as possible. Initially, this requires draining about one half of the water from the bog over a period of several years. Thereafter, the bog is levelled and exposed, and surface peat is harvested as it dries through direct exposure to the air.

The harvested peat can be utilized directly in industrial boilers, or it can be compressed into briquettes which makes it more transportable and amenable for small scale uses such as home heating.

The cost of producing peat is estimated to be approximately \$100/tonne of dry peat.⁽¹⁾ Peat typically has an energy content of about 17 GJ/tonne,⁽²⁾ hence peat production costs are estimated to be in the order of \$6/GJ. In briquette form costs rise 25% to approximately \$7.50/GJ.⁽³⁾

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- (1) Agriculture Canada. This peat cost is for horticultural peat, which utilizes similar processes to that discussed for peat in energy development. No estimate is available for how much of this is capital and how much is operating cost, although a first estimate would be that 1/2 of it is for operating and the rest is amortization of development expenses.
 - (2) Based on an estimate by the Special Committee on Alternative Energy and Oil Substitution that peat resources in the world of 145 billion tonnes are equivalent in energy content to 63.5 billion tonnes of oil. Oil has an energy content of about 38.5 GJ/tonne (ERCB Report 82-F).
 - (3) Special Committee on Alternative Energy, op. cit.

No special user equipment significantly different from that currently in use for other fuels is required for handling or burning dry peat. In residential applications, peat requires what might otherwise be wood or coal burning furnaces and the ability to store volumes of briquettes.

Cost of using peat in residential/commercial space heating applications are estimated in Table II.26. Based on the assumption of a combustion efficiency of 20%,⁽¹⁾ furnace costs of about \$2,000⁽²⁾ and a furnace life of 15 years, the levelized cost per output GJ is estimated at \$37.50. No allowance has been made in this estimate for storage costs.

(1) The burner tip efficiency of peat combustion is only about one third that of oil (assumed to be 65%). Sources: Special Committee on Energy Alternatives, and Stone, Webster, op. cit.

(2) Based on costs of typical multi-fuel heating furnaces.

TABLE II.26

Average Levelized Cost of
Space Heating with Peat

Fuel Cost (\$/input GJ)	7.50
Efficiency Factor	.20
Equipment Cost (\$)	2000
Maintenance (\$/Yr.)	50
Furnace Life (Yrs.)	15
Average Annual Energy Output (GJ/household)	150
Average Levelized Cost per Output GJ	\$37.50

Sources: Agriculture Canada; Special Committee Alternative Energy, op.
cit.

(c) Other Assessment Factors

Technical and Resource Availability Constraints: A major consideration with respect to peat production in Yukon relates to the timing of its development. As outlined in the resource inventory, peatlands in the Yukon are widespread. A number of factors exist, however, which have a major bearing on the time in which it may be developed.

First, development will depend upon a more detailed inventory of peat resources, accompanied by an assessment of its potential for commercial development. Such an inventory is currently being initiated by Agriculture Canada, although no time frame has been established for its completion.

A second factor regards the availability of experienced experts in the field to oversee peatland development. There is currently a paucity of such expertise in Canada, and it is currently dedicated to investigating regions of peatlands with greater near-term development potential (particularly in Ontario, New Brunswick and Newfoundland).

Technological advances may be expected in the next decade which might shorten these time frames and enhance the commercial viability of peat development.

For example, utilization of wet peat involves new technologies which would require greater amounts of energy input at the beginning, but would significantly reduce the costs inherent in the time-intensive drainage process of peat development.

Peat production and energy use technology has been established for some time in Europe but in Canada have only been investigated at the demonstration level. A particular problem in Yukon involves dealing with peatlands in regions of discontinuous and continuous permafrost. Although the actual composition of such peat is no different than in warmer climates, the existence of permafrost has never been previously addressed in peat harvesting techniques. Because of the long lead times involved in preparing peat bogs for harvesting, potential problems arise in dealing with a wide array of climatological changes between the winter and summer seasons. It is known that in southern climates a peat bog may require 4-5 years of preparation time before harvesting can commence. There is no experience which might indicate whether these times would be longer or shorter in Yukon.

In view of the magnitude of the peat resource and the likelihood that utilization will not reach significant levels for some time to come, resource availability would not appear to be a constraint.

Environmental and Economic Impacts: The environmental impacts of peat harvesting are relatively minor. The most significant concern during the development process relates to disposal of significant volumes of water which are removed during the drainage and drying process. After a site has been harvested, land reclamation becomes an important environmental issue.

A notable aspect of peat development is that it is relatively labour intensive during all stages of the process: from drainage, to harvesting, to final land reclamation. This prompted the Special Senate Committee to the House of Commons to recognize it is a significant employment opportunity.

2.11 Hydrogen

(a) Potential Sources and Uses

There is no commercial production or use of hydrogen as an energy source in Yukon. In terms of availability very little elemental hydrogen exists but the resource base is vast since its primary occurrence is in the form of water. Also, hydrogen can be derived from any hydrocarbon such as coal gas, or oil. The problem lies in freeing the hydrogen from its original state in water or as a hydrocarbon.

There are basically two commercial hydrogen production processes used in Canada today. The most commonly used process uses steam reformation or partial oxidation of hydrocarbons. This process essentially "burns" the hydrocarbons (methane or oil) in a wet medium to hinder oxidation and, when carefully controlled, gaseous hydrogen will form as a by-product. Of the hydrogen produced in Canada today, 76% is through methane reformation and 23% from liquid petroleum reformation. These processes are used mainly in the petroleum refining industry where hydrogen is required for upgrading.

The second commercially viable process is through water electrolysis. Although it accounts for only 1% of the hydrogen produced in Canada today, it has a relative advantage because of our abundance of electric energy potential and declining hydrocarbon

resources. Water electrolysis involves the liberation of hydrogen by passing an electrical current through a solution of water and catalyst.

As an energy source hydrogen can be used in a gaseous state for small-scale residential space and water heating or for large scale industrial process heat. In addition, in its liquid state, hydrogen is highly transportable and can be used as motor vehicle and aviation fuel.

(b) Cost Analysis

Hydrogen is a secondary energy source, being derived from hydrocarbons or electricity, depending on the process. Its cost, therefore, will depend on the cost of these primary sources.

In methane reforming it is estimated that approximately 2 GJ of natural gas are required to produce 1 GJ of gaseous hydrogen. In electrolysis, about 1.4 GJ of electricity are required to produce 1 GJ of gaseous hydrogen. The fuel cost of gaseous hydrogen therefore will be two times that of delivered natural gas or 1.4 times electrical energy costs. In addition there would be the capital and operating costs of conversion processes. The latter are relatively small, estimated at \$1.50 to \$1.75/GJ in both processes. Liquefaction of the

hydrogen would entail additional expenditures, increasing the total cost by an estimated 30% over gaseous hydrogen.⁽¹⁾

It is clear that hydrogen is not currently as economic as the energy sources for which it is a substitute, and indeed in the long run it will never be under the methane reforming process. The only way in which hydrogen could become attractive is as a substitute for hydrocarbons, produced by a non-hydrocarbon process, i.e. electricity. If hydrocarbons were to become very expensive, but electricity remain cheap, hydrogen could become an attractive transportation fuel or even possibly an attractive heating source in remote areas. This, however, does not appear likely in the foreseeable future.

(c) Assessment Factors

Technical & Resource Availability Constraints:- The utilization of hydrogen as an energy source has not reached the commercial scale anywhere in North America, although demonstrations on this continent and in Europe, primarily as a transportation fuel, are taking place.

(1) Sources: Committee on Alternative Energy and Oil Substitution, Energy Alternatives, 1981; Ontario Hydrogen Energy Task Force, Hydrogen: A Challenging Opportunity, 1981; R. Reid, "Hydrogen" in Chemical Fuels Technology, 1978.

It is felt that the methods of storing and transporting the fuel are readily developed and are no less difficult than those encountered when handling hydrocarbon fuel. For example, it has been suggested that gaseous hydrogen could be immediately introduced into the natural gas pipeline system, on the basis of 10% volume, with no ill effects on the system and with little incremental investment. Substantial experience with hydrogen at a large scale has already existed for decades at the industrial level. Refineries generate hydrogen by reformation to be used in the cracking processes, and electrolytic hydrogen has been used as a feedstock to the petrochemical industry.

In terms of hydrogen use in Yukon, it is not likely that a hydrogen-based economy can be successfully implemented in just one region or sector of our economy. Although some inroads may be possible on a regional level in the area of home-heating (by introducing 5-10% hydrogen into the natural gas distribution system), the transportation sector would require wholesale changes to user equipment for significant market penetration to occur. For example, in the area of air transport, it is not feasible to develop the storage and engine systems only on a regional scale.

A considerable amount of research and development effort has been placed upon promoting hydrogen and, therefore, a number of technological breakthroughs may arise in the next 10-15 years. One

area of significant potential involves refinements in the efficiency of electrolytic conversion. Technical efficiencies of conversions are currently between 57% to 72% with potential technical improvements yielding up to 85% efficiency.⁽¹⁾

A second area of potential lies in the flexible utilization of hydrogen. Work is currently underway in developing dual-fired hydrogen/gasoline engines which, if adopted, would improve the transition to a hydrogen based economy.

There are a number of appealing attributes to the use of hydrogen as an energy source. First, hydrogen has the potential for use in both space and process heating and in transportation - currently the two end uses which constitute the majority of oil and gas consumption. Therefore, hydrogen offers a means of substantially reducing dependence on imported petroleum products.

Second, production of hydrogen with off-load electric power could result in increased capacity utilization of existing generation facilities or justify the development of a large scale plant. In either case lower unit costs to other Yukon electricity users may result. Nonetheless, as noted in section (b), it is doubtful that hydrogen will be economically attractive in the foreseeable future.

(1) Committee on Alternative Energy & Oil Substitution, op. cit.

Environmental and Economic Impacts:- The main environmental benefit of utilizing hydrogen as a fuel is that it is "clean" burning in that its only combustion by-product is water. Earlier concerns of its explosive nature have been adequately dealt with to the extent that its storage and transportation are no more difficult or dangerous than storing and transporting hydrocarbons.

The potential economic impacts of hydrogen are substantial and would derive from the construction and operation of production facilities, the reduction of expenditure leakages outside Yukon for fossil fuels, and the creation of economies in electricity production.

2.12 Municipal Waste

(a) Potential Sources and Uses

There are no existing uses of municipal waste for energy purposes in Yukon. Potential uses, as with other forms of biomass, include generation of electricity and heat by means of steam boilers, heating kilns or gasification.

Whitehorse would be the only community in Yukon with a population and waste volume possibly large enough to establish a waste-to-energy facility.

(b) Cost Analysis

On the assumption of waste generation of 2kg/capita/day, organic material content of 75%, and an average energy content of 11 GJ/tonne,⁽¹⁾ a community the size of Whitehorse produces municipal waste with an annual energy potential of some 160 GJ/year. This volume of waste and energy potential would support a power plant of 0.8 MW capacity.

In Table II.27, the cost factors and average levelized cost of producing electricity in such a plant are shown. The average levelized cost is estimated at \$29/GJ of electricity output if the facility would be operated as a base load plant. If operated at a low

(1) For sources see Table 27.

load factor, comparable to that assumed for diesel, the unit costs would be higher at \$42/GJ. It should be noted that the capital costs estimates are based on larger facilities and therefore may be understated.

TABLE II.27
Average Levelized Cost
of Waste-Generated Electricity in 0.8 MW Plants

	<u>Base Load</u>	<u>Low Load Factor</u>
Plant Capital Cost ('000\$)	2000	2000
Plant Operating cost ('000\$/Yr.)	340	236
Capacity Factor	.70	.38
Plant Life (Yrs.)	35	35
Average Levelized Cost per Electricity Output in GJ	\$28.83	\$41.71

Notes:

- (1) Assumes electric energy conversion efficiency equivalent to approximately 15% of the energy content of the municipal waste.
- (2) Operating costs include solid waste requirement of 10,350 tonnes per annum at \$22/tonne in base load case; 5,620 tonnes per annum at \$22/tonne in low load factor case.

Sources: B.C. Hydro, op. cit.; Sweeney & Poray, Solid Waste Resource Recovery Strategies and Railbelt Recycling Applications.

(c) Other Assessment Factors

Technical and Long Term Resource Constraints:- There are currently 7 large municipal waste incineration plants with a total capacity of almost 4,000 tonnes of waste per day in Canada. Only 1 incinerator in Quebec, which sells steam to a nearby pulp mill, has a regular purchaser of the energy generated. However, plans are currently underway in Hamilton to produce electricity from its incinerator for sale to Ontario Hydro.⁽¹⁾

The discussion of technical considerations with respect to the utilization of wood as an energy source generally apply to municipal waste. It is bulky and involves relatively high transportation, handling and storage costs. Its moisture content reduces energy conversion efficiency. Utilization technologies are established but their operation and maintenance is more complicated than conventional technologies.

The simplest waste utilization technologies are the shred and burn or mass burning which involve little or no non-organic materials separation. These are the simplest technologies but require a larger incineration unit.

(1) Energy, Mines and Resources, Report ER 181-4E, op. cit.

The refuse derived fuel (RDF) process involves the separation of the combustible and non-combustible portions of the solid waste stream. Most of the non-combustible materials can then be recycled. Typical processing units include shredders, air classifiers, trommels, magnetic separation, eddy-current separation (aluminum recovery), and froth flotation (glass separation). The combustible portion of the waste stream is a high BTU value fuel which can be co-fired with coal or other biomass in a standard utility boiler or burned in a specially designed dedicated boiler. This latter process has encountered serious operation problems, at least in North America. For example, in a survey of waste-to-energy plants in North America, officials of the Municipality of Anchorage, Alaska found that the majority of RDF plants were temporarily or permanently closed due to technical problems.⁽¹⁾ This study concluded that materials recovery and recycling must occur before materials enter a waste-to-energy facility.

(1) J. Sweeney and P. Poray, *op cit.* B.C. Hydro, *op. cit.*, also assumed mass burn plants for purposes of its estimates since RDF plants were not as successful and because of limited markets for non-combustible waste materials.

Environmental and Economic Impacts:- The most significant environmental concern for waste-to-energy plants is the potential for air pollution. This is offset by the reduction in the volume of wastes requiring landfilling by up to 80%-90%. The remaining ash is not putrescible and therefore does not attract nuisance scavengers.

With respect to economic impacts, incremental employment in the delivery and handling of municipal waste is likely to be negligible. The technology would be largely imported but there could be significant construction employment impacts in Yukon. Operating employment would be relatively minor.

2.13 Interconnection

(a) Potential Sources

Electricity could be supplied to Yukon by means of an inter-tie with power generation developments or load centres outside Yukon. B.C. Hydro, as a member of the Energy Working Group of the Yukon River Basin Study investigated the technical and economic feasibility of interconnection with existing or new generation sites in British Columbia, Northwest Territories and Alaska.⁽¹⁾

The Hydro study concluded that a 500 kV transmission line for each of the interconnection alternatives was technically feasible, although it would not provide a firm power supply.⁽²⁾ The relative low loading of the transmission does not justify a high voltage but long transmission distances required voltages greater than 230 kV.⁽³⁾ Less information was available for the selected Alaska and NWT alternatives but preliminary results indicated that these alternatives would involve greater transmission distance and therefore higher construction and energy costs.

(1) B.C. Hydro, Electric Transmission Interconnection Study, Yukon River Basin Study, Energy Working Group, February 1983.

(2) This is due to the possibilities of a forced outage on the line.

(3) Line losses on small low voltage lines are prohibitive.

Of the B.C. alternatives an intertie from Whitehorse to a proposed new hydro site on the Stikine (Collector site) involved the smallest transmission distance (465 km) and lowest capital and annual operating costs.

Another interconnection possibility not examined in the B.C. Hydro study would be from the most northerly point of B.C.'s existing grid at Ft. St. John. This would involve the construction of a 1200 km line to Whitehorse. However, given the transmission distance involved, it was felt that the capital costs and line losses on such a line would likely be prohibitive.⁽¹⁾

(b) Cost Analysis

The B.C. Hydro study examined the costs of interconnection alternatives for three load scenarios--150 MW, 300 MW, 475 MW. The costs of delivering this power from the proposed Stikine-Collector generation site to Whitehorse are summarized in Table II.28 below.

As shown in the Table, the average levelized cost of transmitting power from the proposed Stikine site to Whitehorse ranges from \$2.40 to \$7.40 per GJ. Clearly, the larger the load the markedly lower the per unit cost. Unfortunately, in the context of Yukon requirements it is the lower end of the range (or substantially lower than that) which is most realistic.

(1) Our preliminary analysis indicated that the energy charge in Whitehorse from this intertie would be in excess of \$70/GJ.

TABLE II.28

Average Levelized Cost of
Transmission for Stikine-Collector
to Whitehorse Interconnection

	<u>150 MW</u>	<u>300 MW</u>	<u>475 MW</u>
Capital Cost ('000\$)	236,678	238,787	240,987
Operating Cost ('000\$/Yr.)	4733.6	4775.7	4819.7
Capacity Factor	.60	.60	.60
Economic Life (Yrs.)	45	45	45
Average Levelized Transmission Cost per GJ	\$7.40	3.73	2.38

Notes:

- (1) Capital costs have been escalated to \$1983.
- (2) Operating costs estimated at 2% of capital costs. Interest charges and depreciation have been excluded from operating costs consistent with levelized cost estimates for other energy sources.
- (3) Losses and generation costs not included.

Source: B.C. Hydro, op. cit.

It should be noted that the delivered cost of electricity through an intertie would not only include the transmission costs but also the costs of generating the power in B.C. Assuming a levelized cost of 30 mills per kWh for Stikine power and estimated line losses of approximately .4% would add \$8.40/GJ to the levelized cost of the power.⁽¹⁾ Delivery of 150 MW at a capacity factor of .60 would therefore cost a total of \$15.80/GJ.

(1) B.C. Hydro used an electricity cost of 29 mills/kWh for calculating the value of line losses. The line loss factor represents a proportion of the energy capability of the inter-tie.

(c) Other Assessment Factors

Technical Constraints:- The single most important constraint to B.C. - Yukon interconnection is that the Yukon load is presently too small to justify the capital costs. At some future point when a significant energy requirement exists in Yukon an intertie might be feasible to the benefit of both regions. The other important constraint to note is that the Stikine project or other northern hydro projects might not be built by B.C. Hydro because of falling load growth. It may be many years before a suitable connection point is available for delivery to Yukon.

When loads justify the expense, an interconnection between two regions can provide immediate back-up power supply to ensure that load can be served when generation sources are out of service, particularly if each utility's generation downtimes are not synchronous. Load diversity (eg. hourly, daily, seasonal) or generation diversity (hydro, coal, diesel) between regions, can also result in economies in generation costs. Larger, interconnected systems, if designed properly, have more constant voltages, operation is more flexible and reliability improved.

On the other hand, each region must ensure that its system is designed and operated so that the impacts of internal disturbances on its neighbor do not extend beyond those already planned and agreed upon. System planning guidelines are essential so that interruptions in one region do not cause further interruptions in the other.

Environmental and Economic Impacts:- Transmission intertie rights of way can have impacts on a number of resources including agriculture, forestry, fisheries, wildlife, and recreation. However, these impacts can be mitigated substantially by appropriate route selection (eg. avoidance of Territorial parks), clearing practises and restriction of access.

The economic impact of transmission lines occurs almost entirely during construction. Aside from right-of-way clearing, direct employment of Yukon residents is likely to be minor.

2.14 Waste Heat Recovery from Diesel Generators

(a) Potential Sources and Uses

A preliminary feasibility study has been commissioned by the Yukon Department of Tourism and Economic Development to examine the viability of utilizing waste heat from the Whitehorse Rapids diesel station to provide the space and water heating requirements for various residential, commercial and institutional buildings in Whitehorse.⁽¹⁾

This study examined the most common types of district heating systems, that is, low and high temperature hot water. Another alternative, steam generation, was not examined because of lower waste heat recovery factors and distribution difficulties.

(b) Cost Analysis

Cost breakdowns for diesel generator waste heat recovery shown in Table II.29 are based on the feasibility study mentioned above. This study examined eight alternative district heating systems, 6 of which were low temperature systems and the remainder, high temperature systems. It should be noted that based on the study's assumptions⁽²⁾ all of the alternatives appeared to be economically feasible but that the low temperature system servicing selected government buildings in Riverdale (Alternative III) was recommended as most appropriate for further detailed study.

(1) Atcor Engineering, Whitehorse Rapids Waste Heat Recovery Feasibility Study: Phase I, Feb., 1982.

(2) For example, that users would be willing to pay as much for waste heat per unit of delivered energy as for existing sources.

This alternative, which is a low temperature system, and the lowest cost high temperature system were selected to illustrate levelized costs for waste diesel heat recovery. As the table shows, average levelized costs for the low temperature system are estimated at \$7.36/GJ and at about \$10/GJ for the high temperature system. As explained below, an important reason for this difference is the lower efficiency factor associated with the high temperature system. The estimates are based on the assumption of 100% matching of heating load and energy available from diesel generators. However, even at a 75% matching the waste diesel heat recovery is competitive with alternative energy sources for space heating in the commercial/institutional sectors.

(c) Other Assessment Factors

Technical and Long Term Resource Constraints:- Low temperature systems (approximately 90°C) allow for maximum waste heat recovery from diesel engines (from both the engine jacket and exhaust) but may be inadequate for the peak heating requirements of certain buildings. Higher temperature hot water systems (approximately 120°C) supply a higher grade heat and pipeline costs per unit of delivered heat are lower. However, water temperature in the engine jacket is generally too high for space and water heating applications. Therefore, only exhaust waste heat is recoverable, resulting in a much lower efficiency factor.

TABLE II.29
Specifications and Unit Levelized Costs
for Selected Diesel Waste Heat Recovery Alternatives^a

System Type	Low Temperature ^b (90°C)	High Temperature ^c (120° C)
Capital Costs (\$'000)		
Plant	1052.6	514.1
Distribution	1726.7	573.5
Engineering and Contingency	1091.8	366.8
Costs to User ^d	1013.4	189.7
Operating Costs (\$'000/yr.)		
Plant	50.9	26.5
Pumping	68.9	5.3
Administration	137.8	63.6
Annual Energy Output (GJ) ^e	93,590	24,120
Economic Life (Years)	20	20
Average Levelized Cost per Output GJ	\$7.36	\$9.97

(a) Source: Atcor Engineering, op. cit.

(b) Selected government buildings in Riverdale and downtown portions of Whitehorse. This alternative (III) recommended as most appropriate for more detailed study.

(c) Selected government buildings in Riverdale.

(d) Building conversion costs.

(e) Average annual heating requirements. Assumes matching of heating load and energy available from diesel generators. Complete matching would not likely be possible since the Whitehorse diesel facility is peaking station.

Such district heating systems are widely used in Europe and are considered to be highly reliable⁽¹⁾ because of the simplicity of equipment and controls, the segregation of jacket water and exhaust recovery systems and the redundancy of connected equipment. Diesel generators can generally be located very close to heating loads, thereby minimizing distribution costs. Experience with district heating systems has shown that administration and marketing difficulties are less of a problem with government than with private sector users.

A major problem with respect to waste heat recovery from diesel generators is the matching of heat availability to heating loads throughout the year. For example, the Atcor study indicated that there would be a summertime deficiency in the heat energy from the Whitehorse Rapids diesel station until the late 1980's, presumably when higher electricity loads will permit greater year round operation of the station. This point also relates to the fact that the most important constraint on the availability of diesel waste heat energy will be the demand for diesel generated electricity.

Environmental and Economic Impacts:- Environmental impacts are unknown, but are not likely to be significant. Construction employment would result for system installation, but operating employment would be negligible. Equipment and materials would primarily be imported.

(1) Particularly if, as assumed in the Atcor study, existing heating systems are retained for back-up.

2.15 Conservation

(a) Existing

No formal measure of the extent of conservation in Yukon is possible. It is certain that the voluntary application of conservation measures in all sectors has become more widespread as a result of rising energy costs.

A number of conservation demonstration projects are now being funded under the CREDA, including:

- (i) Residential retrofit demonstration involving 100 residential dwellings and 2 apartment blocks applying to recipients of the Pioneer Utility Grant.
- (ii) The retrofitting of a number of commercial, institutional and public buildings including an airline hanger, recreation building, warehouse and office building.
- (iii) The construction of new, energy efficient homes.
- (iv) The retrofitting of 6 residential houses in Dawson City built by the Yukon Housing Corporation.

(b) Potential

In addition to the above demonstration projects, two major energy audit programs for existing buildings in the commercial/institutional and residential sectors have been funded by the Yukon Energy Conservation Incentives Program and EMR's Home Energy Programs Division, respectively. These programs were established to identify potential energy savings from a whole range of energy conservation measures.

The residential audit covered 100 homes of all types and recommended a number of conservation measures for each home. The number of measures considered totalled 27, ranging from insulation upgrading to "costless" steps such as thermostat setbacks. The commercial/ institutional audit covered a similar number and range of measures for about 70 buildings to date.

(c) Cost Analysis

Actual costs per unit of energy savings are not yet available for the various demonstration projects, nor for the conservation measures proposed under the energy audit programs. However, hypothetical estimates based on computer simulation models of energy use and the impact of conservation in various types of structures have been developed. These audits provide the basis for the cost analysis below.

Capital expenditures and energy savings associated with a range of individual or package conservation measures are shown in Table II.30. The average levelized cost savings range from less than \$1/GJ to just over \$5/GJ. They clearly indicate how attractive conservation can be relative to virtually all supply alternatives in Yukon.

TABLE 11.30

Costs and Energy Savings Associated with Selected
Conservation Measures^a

	<u>Residential</u>			<u>Commercial</u>		
	Water Tank Insulation	Attic Insulation Upgrading	Overall Audit Results	Attic Insulation	Window Glazing	Overall Audit Results
Capital Costs (\$'000) ^b	.060	0.58	25.99	73.57	34.54	1,625.1
Estimated Energy Savings ^c (GJ)	3.2 ^d	70.0 ^e	514.4	7,503.5 ^f	3,180.6 ^f	44,852.0 ^f
Economic Life (Yrs.) ^g	15	15	15	15	15	15
Average Levelized Costs (\$/GJ)	1.92	.85	5.18	1.01	1.11	3.72

200

- (a) Sources: Yukon Energy Conservation Incentives Program; Energy, Mines and Resources, Home Energy Programs Division.
- (b) Cost estimates assume professional installation and are in nominal dollars for the 1981-83 period. Maintenance costs assumed negligible.
- (c) Assumes displacement of space heating fuels according to their relative importance in the residential sector.
- (d) Assumes displacement of electricity.
- (e) Assumes displacement of mix of space heating fuels as described in footnote c.
- (f) Energy savings by specific fuel types were estimated directly in the commercial audit.
- (g) Longer economic life is possible, but 15 years is assumed to be consistent with various space and water heating supply alternatives.

(d) Other Assessment Factors

Technical Constraints:- Most of the conservation measures considered in Table II.30 are technically very simple and proven⁽¹⁾ although the returns in terms of energy savings can vary widely depending upon the fuels being displaced and the level of conservation already in place.

Perhaps the most serious obstacle to the adoption of conservation measures is that, by definition, their costs are almost totally "up-front". Government incentive programs mitigate these initial costs substantially in the residential sector, but are much less comprehensive and effective in the commercial and industrial sectors. High initial costs pose an even greater barrier if the user does not expect to capture the full benefits from conservation investments, for example, where rental values do not fully reflect differences in energy efficiency.

Environmental and Economic Impacts:- The environmental impacts of conservation measures are negligible, indeed, positive if the impact of investments no longer required in other energy sources are taken into account.

With respect to the economic impacts of conservation measures, they are relatively labour intensive and do not require sophisticated training. The materials involved such as insulation, sealed windows, weatherstripping, devices to improve furnace efficiency and hot water usage, etc. are generally manufactured outside of Yukon, but possibilities for import substitution may exist.

(1) This is not to say that new technologies are not being developed (eg. more efficient electric motors and appliances, gasoline carburetors, furnaces, etc.) but rather that there already exist a number of simple measures which have demonstrated effectiveness.

3.0 UTILIZATION SUMMARY BY SECTOR

3.1 Residential Sector

In Table II.31, the average levelized costs and other assessment factors are summarized for each energy source including conservation, potentially applicable in the residential sector.

As shown in the table, conservation measures (as identified in the recent Audit program) are the lowest cost source. Conservation, of course, will not eliminate the need for some supply source and therefore only serves to displace the energy, not equipment costs of the various supply alternatives. The advantage of conservation, therefore, is somewhat less than shown in the averaged levelized cost comparisons. Nevertheless it is still the best source. Only natural gas, if and when it is made available via the Alaska Highway line is comparable in cost. Of the existing supply sources, wood is the least costly, at almost 30% less than heating oil. Other existing supply sources, electricity and propane are more expensive than heating oil.

TABLE II.31

Residential Sector Multiple Account Summary

Energy Source	Average Levelized Cost per Output GJ	Technical Constraints/ Resource Availability	Environmental Factors	Economic Impacts
1. Conservation - Overall Audit Results	5.20	- front end costs inhibit adoption - wide range of returns depending on existing dwelling and measures selected	- reduces environmental impacts of displaced sources	- employment in installation
2. Natural Gas - Alaska Hwy. offline purchase	7.80	- Alaska Hwy. line may not be built - other natural gas sources much more expensive (2 1/2 to 7 times more)	- pipeline impacts - 'clean' fuel	- employment in pipeline construction - limited on-going employment
3. Wood - air tight	11.20	- well established - in aggregate supply no constraint; may be in some communities	- low in sulphur dioxide emission, high in CO particulates - requires proper forest management in long run	- wood harvesting labour-intensive - local production of wood heaters could be expanded
4. Coal - briquettes	14.70	- costs highly variable depending on source of supply - development costs for small market may be prohibitive	- low in ash and sulphur but still a concern	- coal mining and distribution provides substantial development and on-going employment
5. Heating Oil	19.00	- costs could be somewhat lower with Dempster oil line and Whitehorse topping plant	- air pollution	- existing sources provide limited employment - topping plant would provide construction and some on-going employment
6. Electricity - existing mix of sources	19.50	- costs from new sources of supply (or in diesel areas) generally much higher	- depends on source	- depends on source
7. Propane	25.40 - 27.40	- well established	- 'clean' fuel	- existing sources provide limited employment - propane vapour would provide construction and some on-going employment
8. Peat	37.50	- based on southern examples - resource exists but problems of extraction in north not known	- water disposal - land reclamation	- labour intensive in extraction
9. Solar - active or passive retrofit	48.40 - 98.20	- only feasible as complement to other fuels - lower costs possible combining space with water heat - lower passive costs in new structure	- reduces environmental impacts of displaced fuels	- employment in installation

NOTES:

- (1) Based on tables in previous section. It should be noted that cost estimates are rough, in some cases subject to considerable uncertainty.

Of the potential new supply sources, by far the most attractive is natural gas offline sales from the Alaska Highway line. This would be a very economical source of supply, 60% less costly than heating oil. Gas from other potential supply sources, however, would not be so attractive. In most cases they would be no less expensive than heating oil.

The only other supply source which might be attractive relative to heating oil, and more or less comparable to wood, is coal briquettes. Whether coal briquettes could be developed for such a small market, however, is unclear.

3.2 Institutional/Commercial Sector

In Table II.32, several attractive potential sources for the institutional and commercial sector are identified and their costs and other impacts summarized.

Again, the mix of conservation measures identified in the recent Audit program provide the lowest cost source.

With respect to existing sources, wood chip boilers are very attractive. With respect to potential sources, diesel waste heat⁽¹⁾ recovery and direct geothermal appear attractive. The latter depends on the proving up of an adequate resource and the former depends on the demand for diesel generation. Both, however, could provide lower costs than fuel oil or other existing sources.

(1) There are some limited utilization of waste heat in Yukon, now, for example, space and water heating in Dawson and heating of the dike in Whitehorse.

TABLE 11.32

Institutional/Commercial Multiple Account Summary

Energy Source	Average Levelized Cost per Output GJ	Technical Constraints/Resource Availability	Environmental Factors	Economic Impacts
1. Conservation - Overall Audit Results	3.70	- front end costs inhibit adoption	- reduces environmental impacts of displaced sources	- employment in installation
2. Wood Chip Boiler	6.60	- requires low cost chip supply	- high in CO and particulates	- employment supplying chips - improves viability of local sawmills
3. Diesel Waste Heat Recovery	7.40 - 10.00	- established technology - may not meet full heating loads - demand for diesel generation may be a constraint	- negligible	- small initial employment impacts
4. Geothermal	7.30 - 12.10	- technology well established but not quality of resource - subject to "exploration" risk	- limited	- significant development but most personnel likely to be from outside region

NOTES:

(1) Based on tables in previous section. It should be noted that cost estimates are rough, in some cases subject to considerable uncertainty.

3.3 Electric Power Generation

In Tables II.33 and II.34, the costs and other assessment factors for alternative sources of electricity are shown. Table II.33 shows the costs of the alternatives operating at full potential output. Table II.34 shows the costs of selected alternatives operating at low load factors.

As shown in the tables, in terms of average levelized cost of electricity output the hydro alternatives or interconnections are generally the least expensive source of supply. Other potentially attractive alternatives include natural gas (if gas becomes available from the Alaska Highway line), coal and municipal waste thermal power. Large scale wind also exhibits relatively low energy costs, but the technology at this scale is not proven and the cost estimates somewhat speculative.

It should be noted that a comparison of levelized costs of energy in itself does not determine what the best source of electricity in fact is. That will depend on the nature and size of the electrical system and the magnitude and characteristics of the load which must be met. If a system requires additional peak capacity, but not additional

TABLE II.33

Electric Power Base Load Multiple account Summary

Source	Capital Cost per Kw	Average Levelized Cost per Output GJ	Technical Constraints/ Resource Availability	Environmental Factors	Economic Impacts
1. Selected Large Hydro	2380-5130	10.30 - 30.00	- small Yukon requirements	- depends on site	- construction employment
2. Selected Small Hydro (under 5 MW)	3560-4760	13.60 - 34.60	- limited storage - high "feasibility investment" risk	- depends on site	- construction employment
3. Inter-connection	-no firm capacity	15.80	- costs based on Stikine which may never be built - costs based on 150 MW @ 60% capacity factor - very large relative to Yukon requirements	- right-of-way clearing impacts	- right-of-way clearing employment - limited transmission installation employment
4. Coal (Bonnet Plume)	1746	25.30	- costs based on 70 MW @ 80% load factor - very large relative to Yukon requirements	- air pollution concerns	- in addition to mining there would be plant construction and operating employment impacts
5. Large scale Wind (5MW - 40MW)	1540-2350	21.70 - 27.60	- Not proven reliable at this scale - costs speculative - only displaces fuel which would be zero in case of hydro	- some land requirements	- some installation employment
6. Municipal Waste	2500	28.80	- restricted to Whitehorse location - cogeneration more attractive	- air pollution - reduced land fill requirements	- construction employment, limited operating employment
7. Wood Gasification	5190	53.60	- complicated technology - cogeneration more attractive	- disposal of toxic organic compounds and tars	- construction, minor on-going employment
8. Small Scale Wind (with some storage) (2KW - 40KW)	4500-6690	78.90 - 183.20	- well established - serves only as supplement to other sources	- limited	- installation employment
9. Solar (Photo-voltaics and Power Tower)	6300-10600	183.30 - 220.60	- only displaces energy costs	- limited	- installation employment

NOTES:

- (1) Based on tables in previous section. It should be noted that cost estimates are rough, in some cases subject to considerable uncertainty.
- (2) Output and capacity characteristics vary among the alternatives. Economics of the alternatives depends not only on average energy or capacity cost but on how the output characteristics suit the nature of the demand and existing system.

TABLE 11.34

Electric Power Low Load Factor Multiple Account Summary

Source	Capital Cost per Kw	Average Levelized Cost per Output Gj	Technical Constraints/ Resource Availability	Environmental Factors	Economic Impacts
1. Natural Gas Alaska Hwy.	300	19.70	- flexible in use and timing - limited in location - depends on Alaska Hwy. line	- clean in use	- minor installation employment
2. Coal (Bonnet Plume)	1750	39.20	- based on 70MW plant, large relative to requirements	- air pollution concerns	- construction plus operating employment
3. Municipal Waste	2500	41.71	- restricted to Whitehorse	- air pollution - reduced landfill requirements	- construction employment - limited operating employment
4. Diesel	935	52.26	- flexible in use and location	- air pollution	- minor installation employment
5. Wood Gasification	5192	96.02	- complicated technology - cogeneration more attractive - requires chip supply	- disposal of toxic organic compounds and tars	- construction - some on-going

NOTES:

- (1) Based on tables in previous section. It should be noted that cost estimates are rough, in some cases subject to considerable uncertainty.
- (2) Output and capacity characteristics vary among the alternatives. Economics of the alternatives depends not only on average energy or capacity cost but on how the output characteristics suit the nature of the demand and existing system.

annual energy capacity, then sources which provide capacity (kW) at least cost will be more attractive than those which provide energy (GJ) at least cost. Or, if a system requires a small increment of energy, it is very likely a higher cost small scale source will be preferable to a lower cost large scale source.

The preferred method of identifying the best electricity supply alternative is to compare the present value of total system costs associated with feasible generation expansion alternatives. The averaged levelized energy and capacity costs as shown in the tables simply indicate which sources should be considered in assessing alternative expansion possibilities.

3.4 Transportation Sector

Few energy sources can effectively be used in the transportation sector. Existing sources in Yukon include refined petroleum products and propane. Potential sources include compressed natural gas and hydrogen.

While detailed cost analyses of these fuels have not been undertaken, the following general points can be made. Firstly, both hydrogen and gas are not likely to be viable or attractive in Yukon for many years. Hydrogen is simply too expensive and compressed natural gas requires a compression and distribution system which is likely to be prohibitively expensive given the size and nature of the Yukon market.

With respect to propane and refined petroleum products, preliminary analyses suggest that the two sources are roughly equivalent in cost for average automobile use. The conversion costs to propane are offset by lower fuel costs per km. For above average use, propane would be slightly preferable; for below average use, RPP's would be preferred. Generally however the differences are not great.

III. CONCLUSIONS AND RECOMMENDATIONS

This study is basically intended as a source or reference document rather than on a detailed analysis of energy policy and programs for Yukon. Nevertheless, certain conclusions and recommendations with respect to supply and energy utilization do emerge from this background study and are summarized briefly below.

1.0 INVENTORY SUMMARY

Overall energy potential is not estimated in this study because of lack of information, measurement problems and the difficulty of reconciling data for renewable and non-renewable sources. However, it is clear that Yukon has large reserves of both renewable and non-renewable sources.

With respect to renewables, hydro potential is very large, though the exploitation of this resource is constrained by the size of Yukon electricity demand and locational factors. Electrolytic hydrogen can be viewed as an alternative, but much more costly form of hydroelectric potential. Wood and wood waste, though much smaller in potential than hydro, is also a significant energy resource in Yukon. In total, Yukon's wood resource far exceeds current requirements. For specific communities, however, wood may not be available in sufficient volumes or at acceptable cost. The magnitude and quality of geothermal resources is unknown.

Solar and wind are vast sources of renewable energy. This total energy potential far exceeds all other energy sources in Yukon. However, the 'low density' of solar and wind make the amount that can actually be captured very much less than the potential. The economics of their exploitation further constrain the usefulness of these sources.

With respect to non-renewables, Yukon has very large reserves of oil and gas and to a lesser extent coal. Again, exploitation of these resources is constrained by the size of the Yukon market and the remote locations of the resource. Without the establishment of export markets and new delivery (eg. pipeline) systems, development will probably be very limited.

2.0 UTILIZATION SUMMARY

There are a wide range of energy forms that can be used to meet Yukon's energy requirement. Alternatives currently in widespread use include refined petroleum products, electricity, propane and wood. Alternatives which are currently used on a limited or demonstration level basis include coal, wind, solar, geothermal and waste diesel. Alternatives which are not currently used, but which could be considered or available in the future include natural gas, peat, municipal waste, hydrogen and interconnection. All of these alternatives were analyzed in the energy utilization review.

While not a source of energy supply, increased conservation measures were also considered in the utilization review. The results of the review indicated that conservation opportunities identified for the residential and commercial/institutional sectors in the recent audit program in fact constitute a very attractive method of meeting Yukon requirements. The estimated cost savings per output GJ are lower than the cost of all of the existing and potential supply sources considered.

Of existing supply sources, wood and coal appear attractive in heating applications. Waste diesel and geothermal also may offer relatively low costs for direct use in institutional and commercial uses. All of these sources may provide energy supply at costs competitive with or lower than refined petroleum products, with greater economic impacts and less dollar "leakage".

Of the potential new supply sources, natural gas would appear to be the most promising alternative. Indeed, if available off an Alaska Highway line, natural gas would be by far the most economical source of energy in (excluding conservation) Yukon. If the Alaska Highway line is not built, natural gas could still be made available in Yukon, either from indigeneous sources or in the form of LNG from B.C.⁽¹⁾ These sources of gas, however, are much more expensive than the Alaska Highway line and their advantage relative to other energy forms is greatly diminished or lost. Levelized energy costs for peat and solar even though based on southern examples, were the highest of all sources examined.

With respect to electric power generation, hydro would appear to offer the lowest cost source of baseload supply. Natural gas would be the most economical source of supply at a low load factor, but this obviously depends on the construction of a pipeline. Coal, inter-connection, large-scale wind and municipal waste may also have merit, but are subject to serious limitations -- coal by the minimum economic scale of development; inter-connection by the scale problem and interruptibility; wind by the uncertainty of performance plus the fact it would only serve to displace fuel but not firm capacity; and municipal waste by the limited locations (essentially Whitehorse) where it may be feasible. For purposes of providing electricity in remote, off-grid locations, it is not clear that any alternative other than a suitable small hydro site (if one were nearby) would be more economical than diesel.

(1) If an LNG facility is in fact constructed in B.C.

3.0 RECOMMENDATIONS - AREAS FOR FURTHER STUDY

Energy sources which appear promising, but for which further information and analysis are required include wood, coal, geothermal, hydro and large scale wind or wind assisted diesel.

Wood was identified as a very attractive energy source for heating applications. Areas where we would recommend further investigation are as follows:

- The inventory of wood appears sufficient from a Yukon-wide perspective, but access for specific communities is unclear. More research on wood inventory is required on a community-specific basis
- While residential heating with wood appears economically attractive, it is posing an apparent environmental problem. Methods of mitigating this problem should be addressed;
- Dedicated wood chipping operations appear to offer very low wood fuel costs. The extent to which such operations could be expanded in Yukon should be considered.

There are extensive reserves of coal in Yukon and coal was identified as a potentially attractive energy source for residential and commercial heating and electrical generation purposes. However, much more information is required on the economics, particularly for smaller scale heating applications based on local resources.

Geothermal was identified as a potentially attractive source of energy for direct heating and possibly electric power generation. At this point in time, however, data on geothermal resources in Yukon are quite general. Research is required and recommended to assess (i) the quality of specific promising geothermal locations and (ii) the feasibility of their exploitation and use.

In terms of sources of electricity supply, hydro was identified as perhaps the most economical source of supply. Of course the characteristics and location of specific sites will govern their feasibility and attractiveness. Continuing investigation of, in particular, small hydro sites is clearly very important for meeting growing Yukon electricity requirements.

Other sources of electricity supply which should be investigated further are coal-fired thermal, geothermal (subject to further inventory work), large scale wind and wind assisted diesel. The economics of co-generation of heat and electricity from locally sourced biomass such as wood, coal, peat and municipal waste merit further investigation. More detailed research on the utilization of waste heat from diesel generators is clearly warranted.

The terms of reference for this study request an assessment of the extent to which alternative power sources can defer hydro-electric development. Clearly, on the basis of the inventory and

utilization review there are numerous options which could displace hydro for many years. At this point in time, however, it appears that many of these options may not be feasible (in terms of scale) or economic (relative to hydro). The further investigation which we recommend above will assist in determining if this is indeed correct.

It must be emphasized that when assessing the relative merits of alternative sources of electric power, it is the impact of each alternative on total system costs that must be considered, not its unit energy or capacity costs on a stand alone basis. How an alternative fits into the total system in terms of the energy and capacity it offers relative to that which is required, is the key question. The ranking of projects on a stand alone basis simply serves to indicate which projects are best to consider in this broader context.

Finally, while the study has focussed on sources of energy supply, the common sense conclusion that measures to reduce demand can be equally if not more economically attractive is clearly supported. Conservation should receive continuing emphasis in Yukon government energy policy and programs.

APPENDIX A

CONVERSION AND ENERGY CONTENT FACTORS

1. Energy Conversion Factors

1 GJ = 277.8 kWh
1 GJ = 947,800 Btu

2. Energy Content Factors

Wood	7.1 GJ/m ³ (of solid wood)
Natural Gas	.031 GJ/m ³
Crude Oil	40 GJ/m ³
Propane	.025 GJ/litre
Heating Oil	.040 GJ/litre
Gasoline	.035 GJ/litre
Diesel	.039 GJ/litre
Coal	5-10 GJ/tonne
Peat	17 GJ/tonne
Municipal Waste	11 GJ/tonne
Hydrogen	151 GJ/tonne